Einstein Telescope

2021 ESFRI Roadmap update

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ET Science in a nutshell

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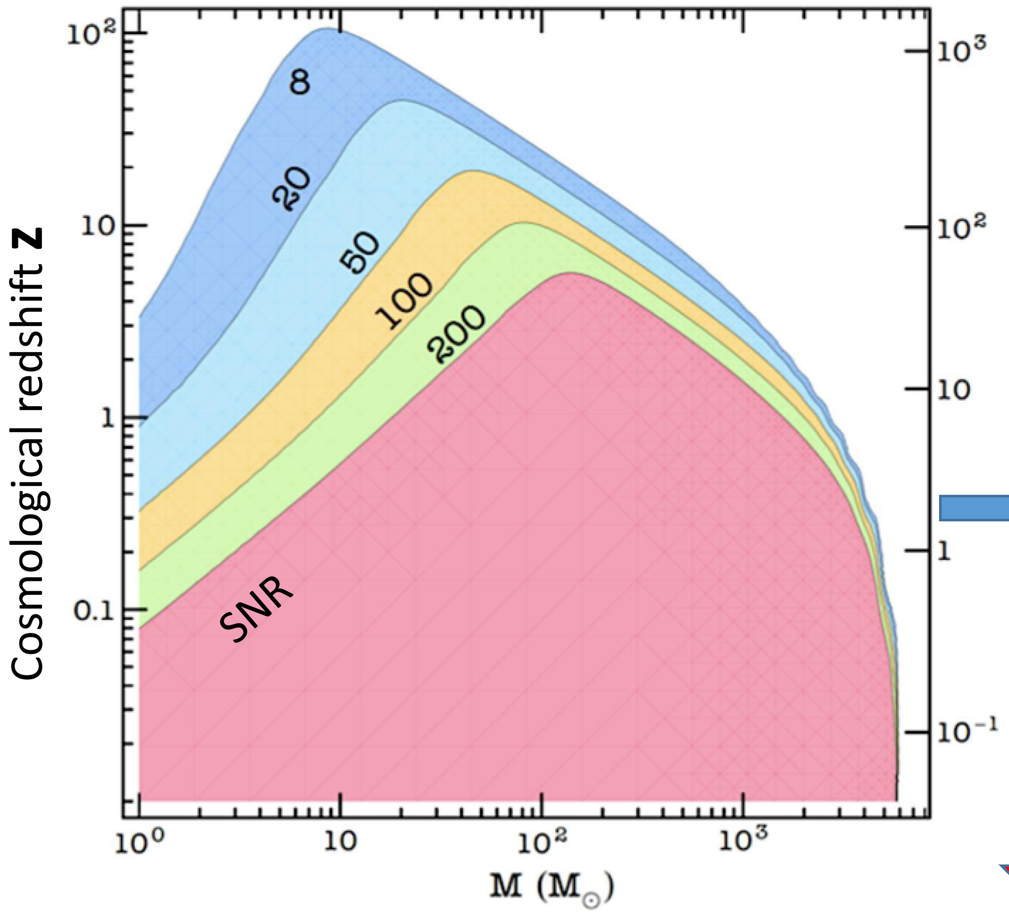
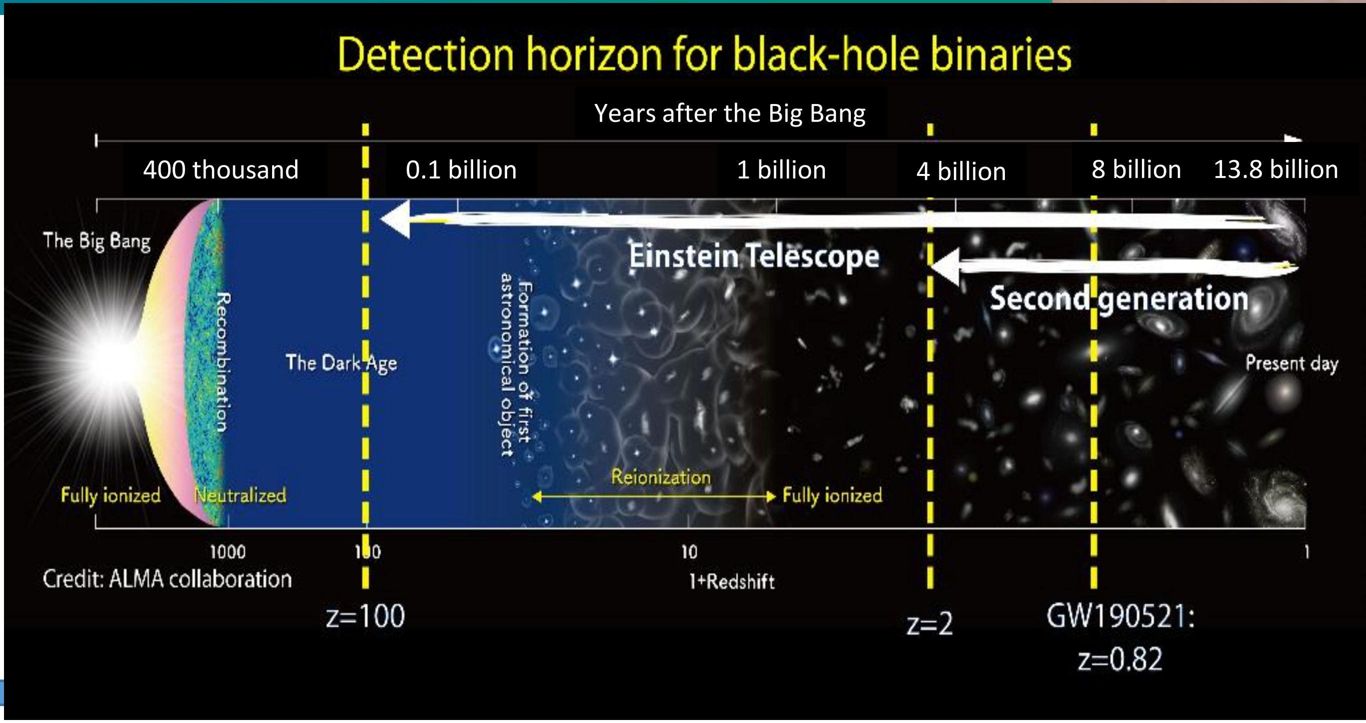


Remote Universe

Nearby Universe



The combination of

- distances and masses explored
- number of detections
- detections with very high SNR

will provide a wealth of data expected to generate **revolutions in astrophysics, cosmology and fundamental physics**

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ET Science in a nutshell

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ASTROPHYSICS

- **Black hole properties**
  - origin (stellar vs. primordial)
  - evolution, demography
- **Neutron star properties**
  - interior structure (QCD at ultra-high densities, exotic states of matter)
  - demography
- **Multi-band and -messenger astronomy**
  - joint GW/EM observations (GRB, kilonova,...)
  - multiband GW detection (LISA)
  - neutrinos
- **Detection of new astrophysical sources**
  - core collapse supernovae
  - isolated neutron stars
  - stochastic background of astrophysical origin

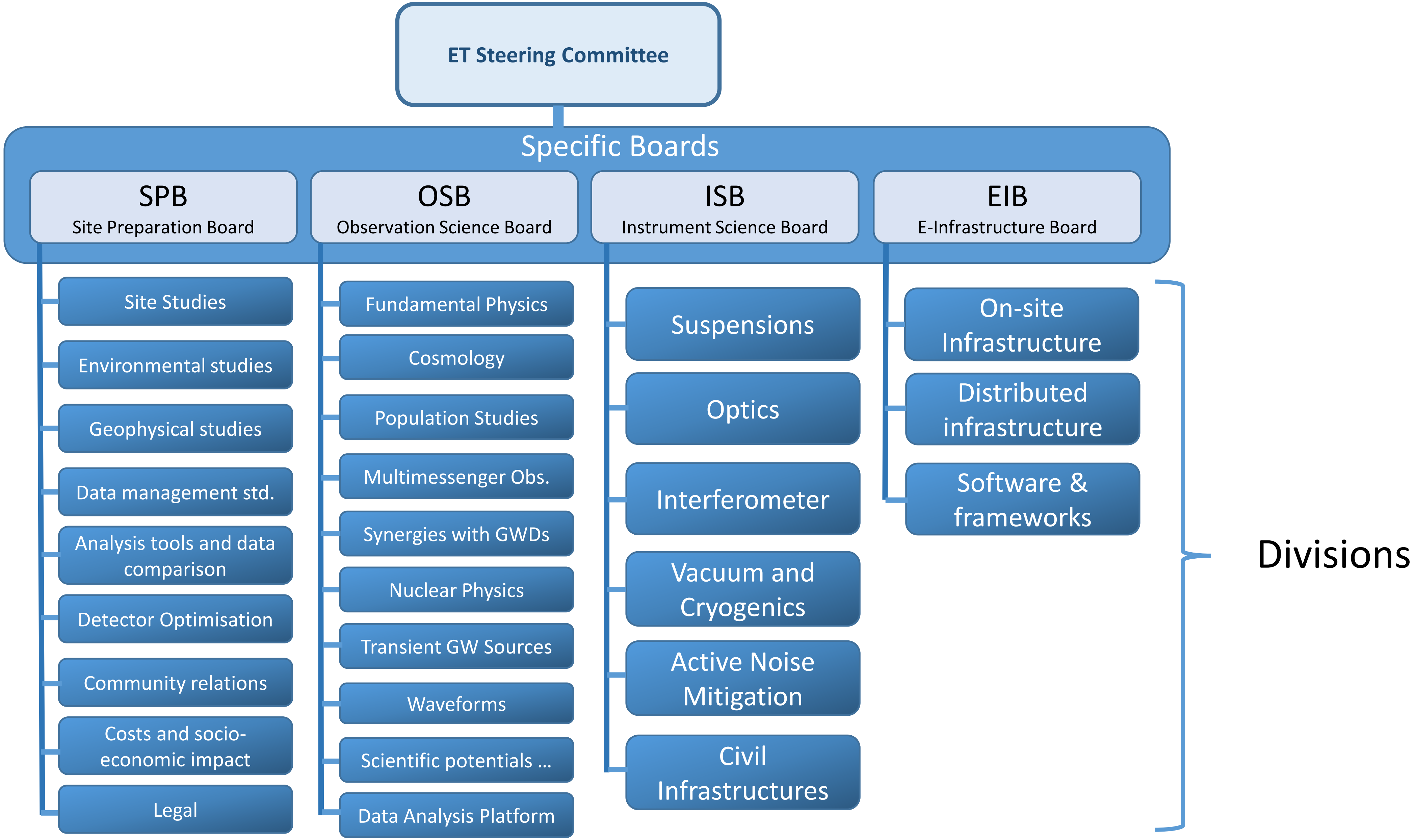
FUNDAMENTAL PHYSICS AND COSMOLOGY

- **The nature of compact object**s
  - near-horizon physics
  - tests of no-hair theorem
  - exotic compact objects
- **Tests of General Relativity**
  - post-Newtonian expansion
  - strong field regime
- **Dark matter**
  - primordial BHs
  - axion clouds, dark matter accreting on compact objects
- **Dark energy and modifications of gravity on cosmological scales**
  - dark energy equation of state
  - modified GW propagation
- **Stochastic backgrounds of cosmological origin**
  - inflation, phase transitions, cosmic strings

Since September 2020...

- The ET collaboration made significant progress in the internal organisation:
  - **ET collaboration**: ET symposium (30/11-03/12/2020), about 710 collaborators, kick-off event for the formal constitution of the ET scientific collaboration
    - Defined technical boards needed in the preparatory phases
      - Standard structure for the “specific boards”
      - Mandate for each board
      - Appointment of almost all the division and WP chairs
  - **ET project & ET site**: :
    - See answers to questions 7-10 by Jo van den Brand

ET collaboration current organisation



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Instrument Science Board

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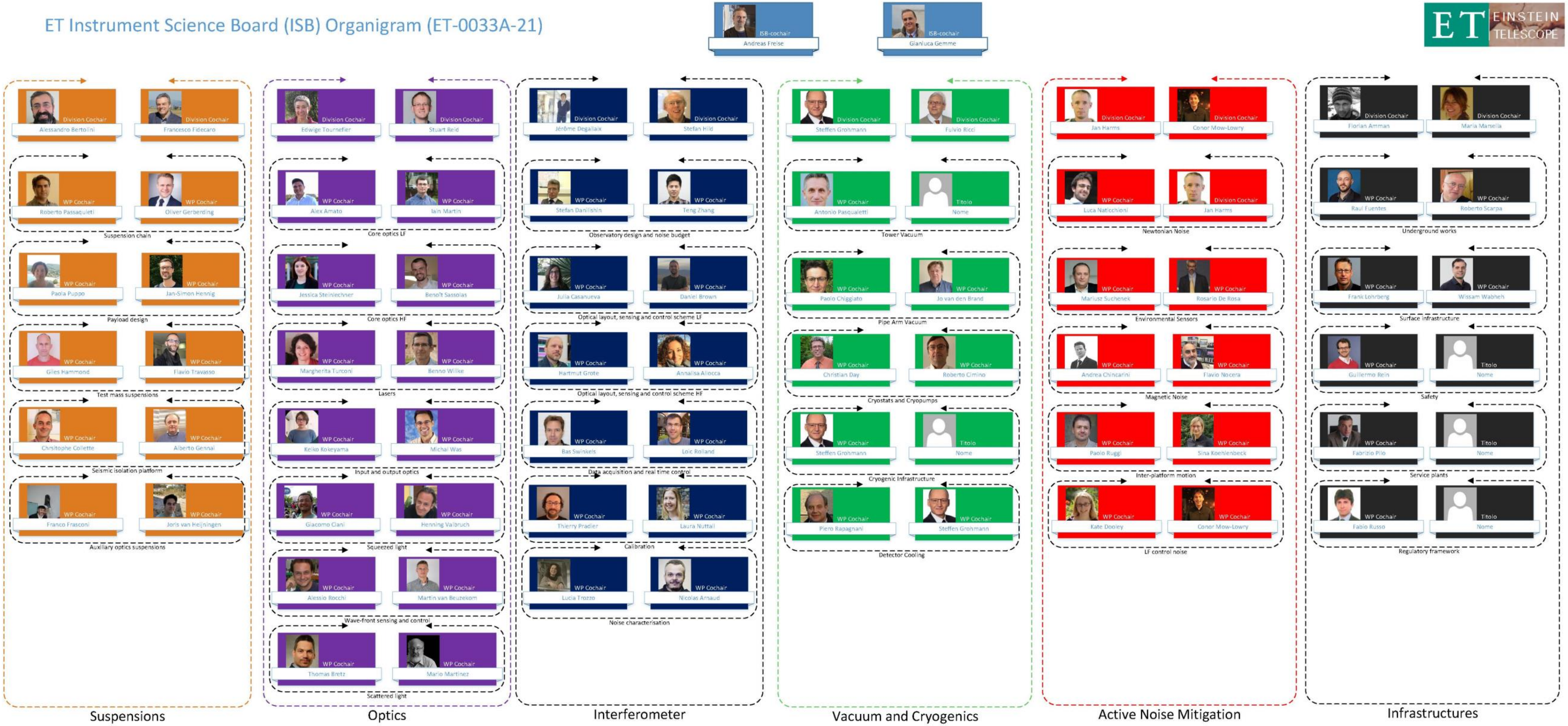

Question 1:

- A sizable number of technical challenges exist to reach the required sensitivity by the Einstein Telescope.
- What are the particularly critical items requiring further R&D effort and the associated risks and their potential impact on the programme?
  - Is there any plan in place to mitigate against the risks?

TRUE, ET will allow us to develop a lot of advanced technology!

We identified 3 critical items potentially causing intermediate scenarios. The impact on science targets have been evaluated

YES! A set of technology development facilities have been identified

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Q1: Enabling Technologies

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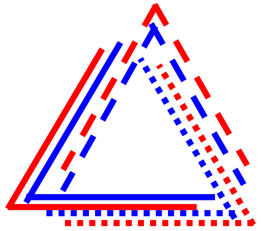
- The multi-interferometer approach asks for two parallel technology developments:



- **ET-LF:**
  - Underground
  - Cryogenics
  - Silicon (Sapphire) test masses
  - Large test masses
  - New coatings
  - New laser wavelength
  - Seismic suspensions
  - Frequency dependent squeezing

- **ET-HF:**
  - High power laser
  - Large test masses
  - New coatings
  - Thermal compensation
  - Frequency dependent squeezing

Challenging engineering

New technology in cryo-cooling

New technology in optics

New laser technology

High precision mechanics and low noise controls

High quality opto-electronics and new controls

Evolved laser technology

Evolved technology in optics

Highly innovative adaptive optics

High quality opto-electronics and new controls

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Q1: Critical technological aspects

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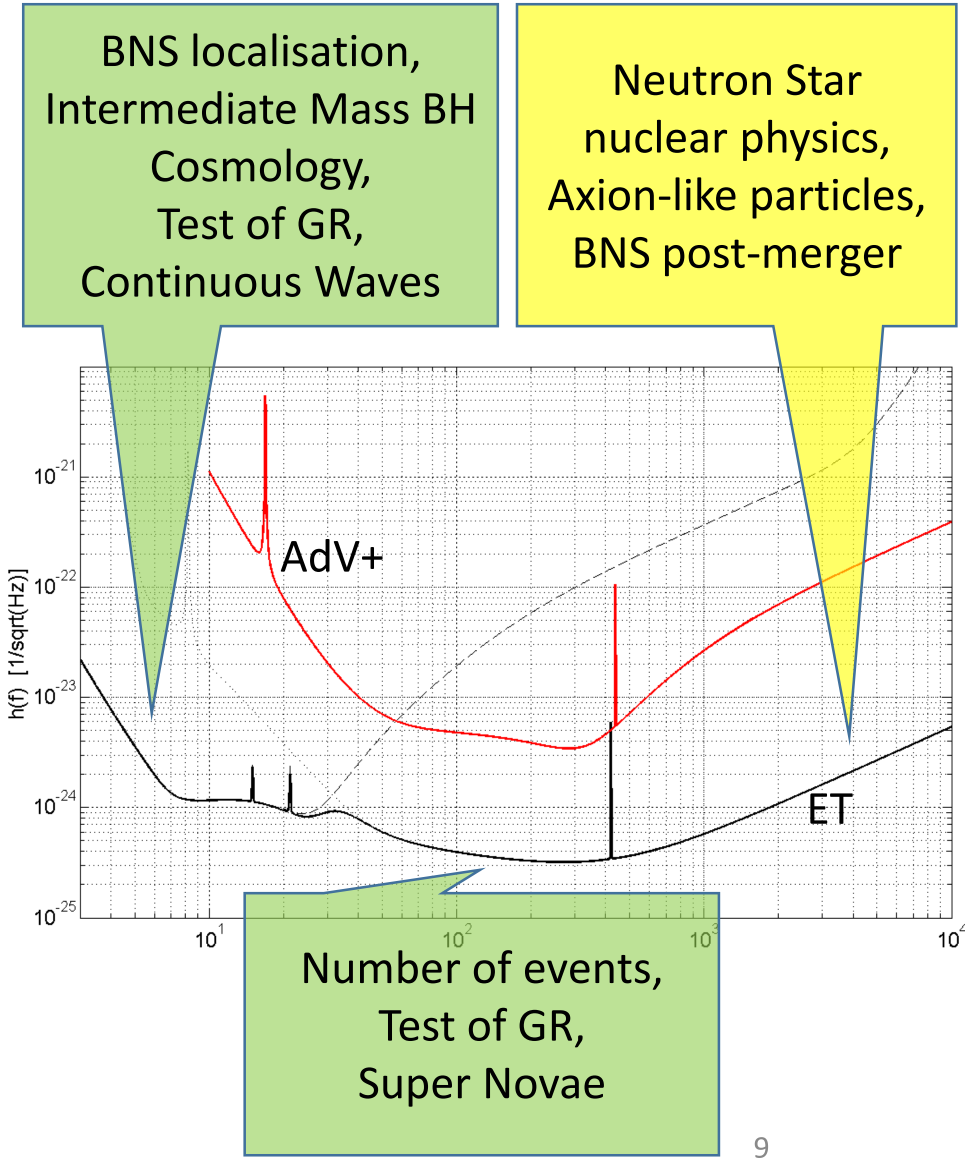
- **High power circulating in the ET-HF detector**
  - The management of this power (~3MW) and the control of thermally induced aberrations of the ET-HF optics are still under investigation

Potential impact on sensitivity at **High Frequency**

- **The low-frequency motion requirements for ET-LF**
  - Achieving low frequency performance is a challenge in 2G and 3G detectors.
- **Cryogenics in ET-LF**
  - The impact of cryogenic infrastructure on ET-LF's low-frequency sensitivity and the choice of materials for ET-LF's optics are still under investigation

Potential impact on sensitivity at **Low Frequency**



Q1: Technological Risk mitigation

- The most relevant risk mitigation tool for ET-HF is the development of the Advanced Detectors expected in the next 5-7 years
  - The update programme of the 2G/2G+ interferometers is crucial
- In the low frequency regime and in the cryogenics aspects there are important risk reduction activities:
  - KAGRA experience
  - ETpathfinder
  - SarGrav
  - A network of cryogenic and technological facilities in Europe (Rome, Hannover, …)

Question 2

- It is proposed to upgrade the current 2nd generation gravitational wave antennas and to continue operating them in parallel with the ET operation, which will require substantial resources. What are the compelling scientific justifications for this?

In the ramp-up phase, ET significantly benefits from the **global network** of 2G detectors to **localize events**

ET-design has good localization capability for binary neutron star mergers, operating with 2G increases the number of well localized events

ET will significantly benefit from operating in a network of 3G GW detectors, such as Cosmic Explorer and the contributions of 2G will become negligible

CAD drawing of the proposed LIGO India observatory

Q2: The global GWD network

ET+ 2G detector network (Virgo, LIGO-Hanford, LIGO-Livingston, LIGO-India, KAGRA)

Increase numbers of localized binary neutron star mergers

Detected events per year with sky-localization	< 20 deg^2	< 100 deg^2
ET	125	1230
ET+KI	233	2640
ET+HLKI	435	4420
ET+HLKIV	437	4420

Kagra and LIGO-India improve the sky localization

Due to its close proximity to ET, Virgo **does not improve** sky localization

Operating with 2G detector network improves the ET sky-localization capability up to a redshift of about 0.6 (3.5 Gpc)

→ **Multi-messenger science, cosmology, nuclear physics**

Question 3

- The number of gravitational wave detections by the ET will be significantly larger than that by the 2G network, which may be an issue for the other observatories to make follow-up measurements.
- Has the possible impact for those observatories and their capacity to respond to alerts been evaluated?

Only a fraction of the 10^5 binary compact object mergers detected by ET per year will have a completely characterized Electro-Magnetic (EM) counterpart

A **hundred of joint detections per year up to high-z → reasonable telescope time** request with an **enourmous scientific return** for relativistic astrophysics, nucleosynthesis, nuclear physics, fundamental physics, and cosmology

Q03: Multi-messenger observatories

ET will operate in synergy with a new generation of innovative observatories

Q03:Multi-messenger observatories

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SEARCH PHASE → wide field of view observatories

- **REMOTE UNIVERSE: HIGH ENERGY SATELLITES**

γ/X-ray satellites (such as SVOM, Einstein Probe, the mission concepts THESEUS and AMEGO) observe in **survey mode**
→ **no necessity to interrupt other observations**

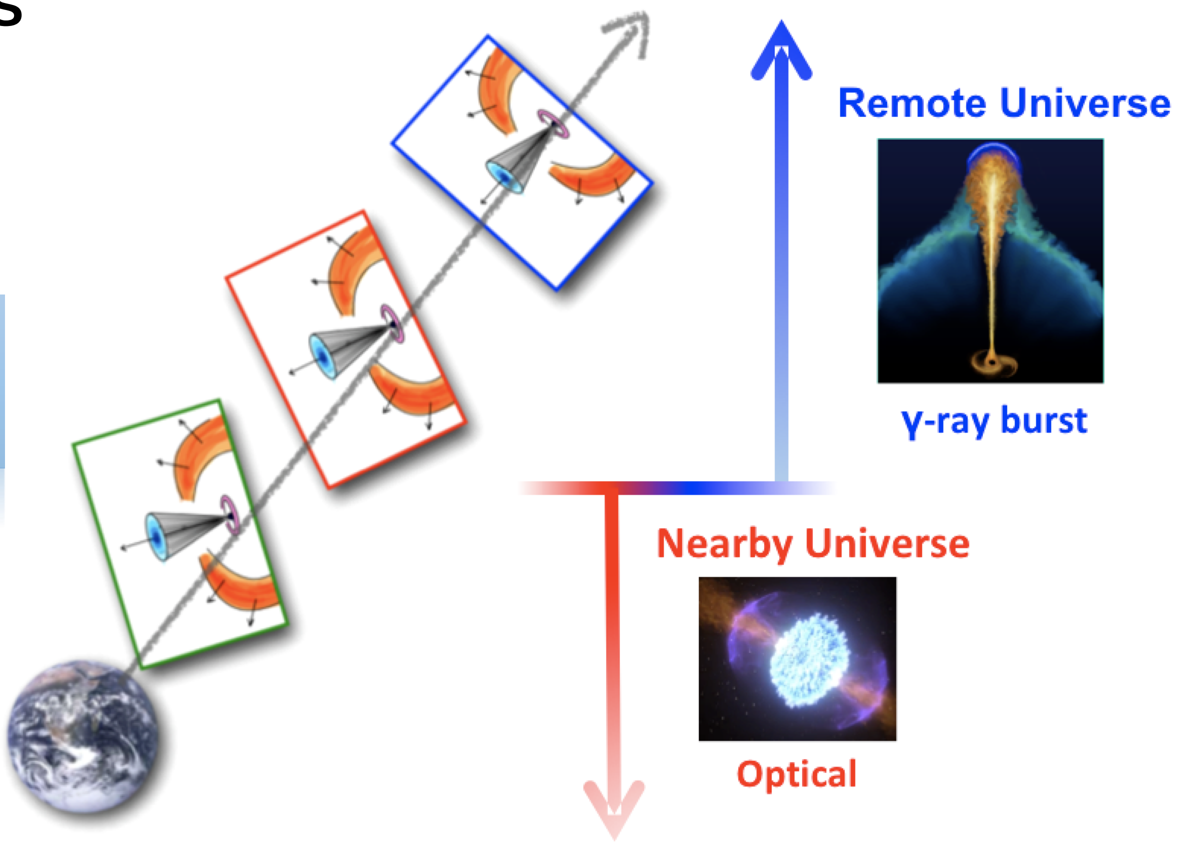
THESEUS-ET joint detections: 10 per year

- **NEARBY UNIVERSE: OPTICAL TELESCOPES**

→ **necessity to ask telescope time to follow-up well localized GW triggers**

A hundred of counterparts per year can be identified asking 10% of the Vera Rubin telescope time

VERA C. RUBIN OBSERVATORY



Q03:Multi-messenger observatories

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CHARACTERIZATION PHASE: spectroscopy and deep observations

- **The most time expensive phase**

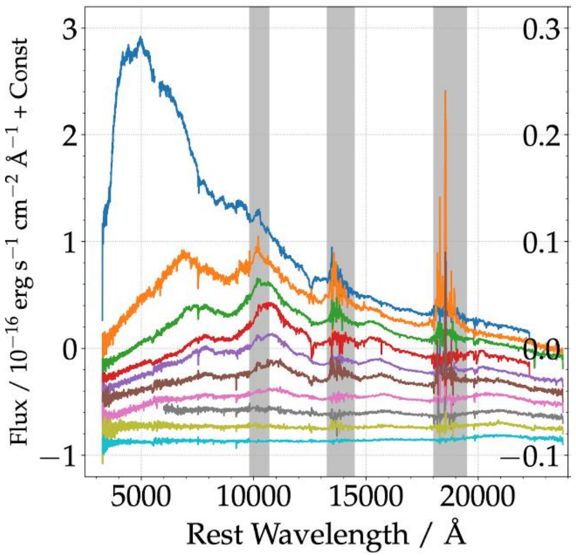
HOST GALAXY REDSHIFT

- Spectroscopic surveys (WAVES@ESO, DESI, MSE) will measure the z for several milions of galaxies

A hundred detections per year will have redshift measurements

TRANSIENT SPECTRA and DEEP FOLLOW-UP

- Time request in expensive larger telescopes, such as, JWST, TMT, VLT@ESO, ELT@ESO



Several tens of transients per year are expected to be completely characterized

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Question 4

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- What is the volume of data that will be generated during the operation of the ET?
- What is the required storage and communication capacities to cope with this?
- Do the foreseen analyses of signals impose particular requirements on the computational architecture to be employed (for example, tensorFlow vs more traditional HPC)?

Few tens of PB

OK

Moderate bandwidth (50-100Gbs) network and “moderate” storage capabilities will be enough

OK

It requires code and algorithm optimisation, R&D, and we expect to use “traditional” HPC

OK

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Q04: Data production, networking and storing

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- Current GW detectors are writing about 1PB per year of raw data per detector
  - Pre-processed data for user analysis is more than 1 order of magnitude smaller
- Raw data doesn't grow much with increasing instrument sensitivity
- **In ET we expect about few tens of PB of raw data per year**
  - As a comparison, each of the two largest LHC experiments are expected to need at least 1 EB of disk storage for Run 4.

Data Production

- **Very reliable moderate-bandwidth (50-100Gb/s) network links** for data export between the ET and the sites holding custodial storage are required
- **Reliable and fault-tolerant, low-latency, low-bandwidth global networks** are required to support multi-messenger astronomy.
- **We expect the existing network infrastructure in Europe will suffice and exceed ET needs**

Network

- In HEP the available infrastructure is aimed to evolve towards a "Data Lake" complemented by a caching Content Delivery Network architecture
  - **This infrastructure will vastly exceed ET needs**

Storage

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Q04: Computing needs

- Current computing needs of the entire GW network are about 1/10 of an LHC experiment[3]
- But in ET the event rate will be 10^3 - 10^4 times the current one
  - Analysis of the “golden” events (EM counterparts, high SNR or “special” events) would already be within reach using current technologies
    - O(500) events per year = 12.5MHS06-y per year, the same order of magnitude of a LHC experiment in Run 4
  - **Plenty of margin for optimization**:
    - Already in O3 CPU energy per event is smaller than O2
    - Down-sampling of the data stream for long duration events
    - Hierarchical methods
    - Adoption of leading-edge technologies
      - Artificial Intelligence and Machine Learning[4,5]
      - CUDA GPUs and HPC (FPGA and new architectures such as TPUs still to be tested)
      - HPC role is expected to grow with the SNR (Numerical relativity!) and use of AI/ML

Question 5

- Data and analysis tools will be made available publicly after the proprietary period.
  - Will some be kept for internal use within the collaboration?
- Please elaborate, especially on the criteria eventually used to open data and tools and the process for granting special projects to access data.
- Will all the data ultimately be made available to the general community according to the FAIR principles?

Only for a limited period of time after the acquisition, for calibration and internal analysis

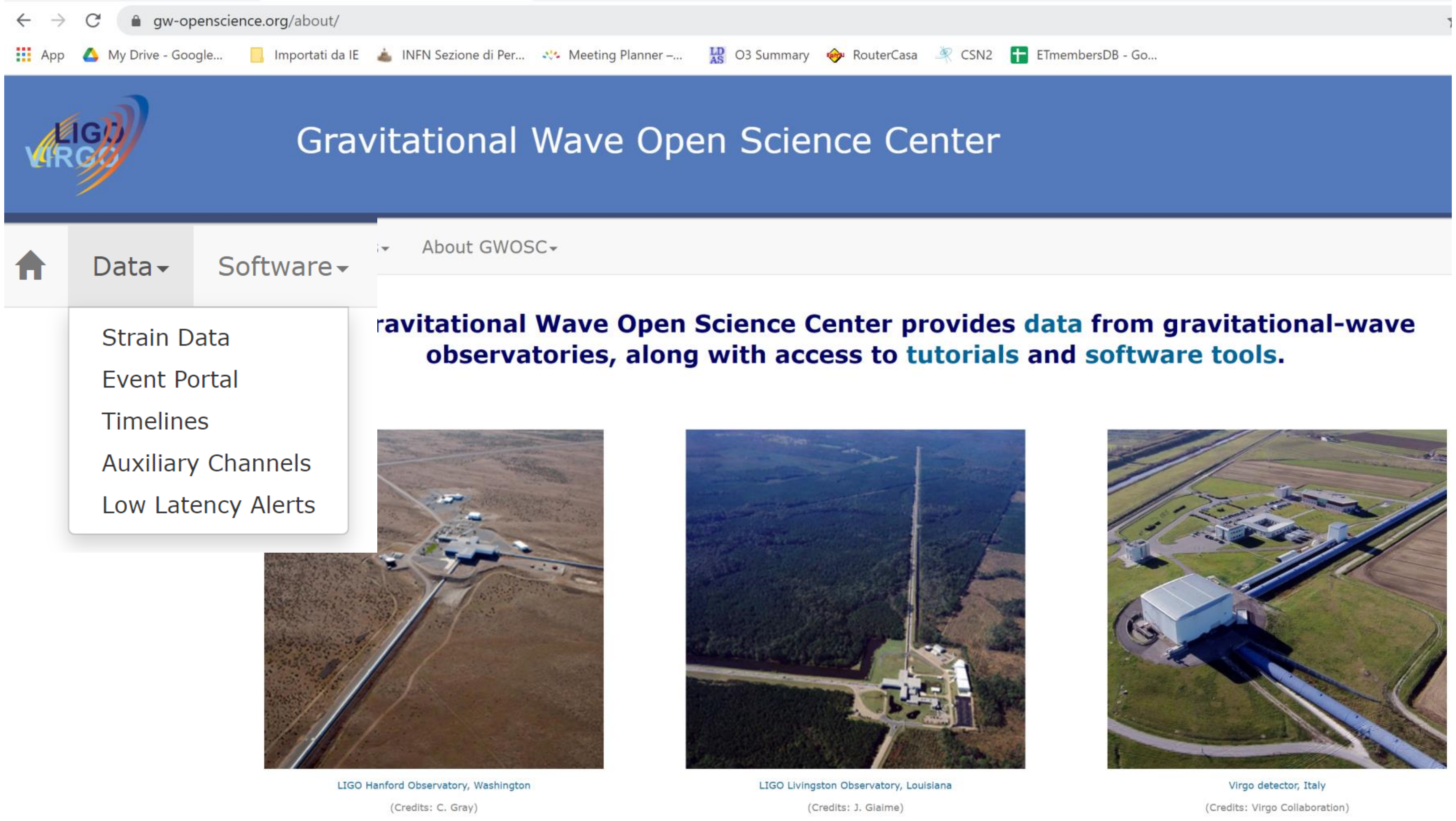
Data will be Open Access, after the proprietary period. Alerts will be public and open from the beginning

Yes! The GW community is already working to meet the FAIR principles

Q05: FAIRness of ET data

- Based on GWOSC: https://www.gw-openscience.org/about/

Findable:
data will be enriched by metadata, findable through indexes in a searchable resource, adopting standard method



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Q05: FAIRness of ET data

EINSTEIN TELESCOPE

- Based on GWOSC: https://www.gw-openscience.org/about/

Findable

Accessible:
data will be accessible through open access repositories using standard protocols and standard authentication protocols, when needed

LIGO and Virgo Data

Click for data usage notes Please Read This First!

The LIGO Laboratory's Data Management Plan describes the scope and timing of LIGO data releases.

Events and Catalogs

Event Portal

Large Data Sets

For users of computing clusters or if accessing large amounts of data, CernVM-FS is the preferred method to access public data.

CVMFS Docs

Auxiliary Data Release

Time Range: 3 hours around event GW170814 (August 14, 2017)
Detectors: H1 and L1
Description: Around 1,000 channels that monitor the LIGO instruments and surrounding enviornment.

Auxiliary Data

O2 Data Release

O2 Time Range: November 30, 2016 through August 25, 2017
Detectors: H1, L1 and V1

4 kHz Data | 16 kHz Data | Documents | Timeline

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Q05: FAIRness of ET data

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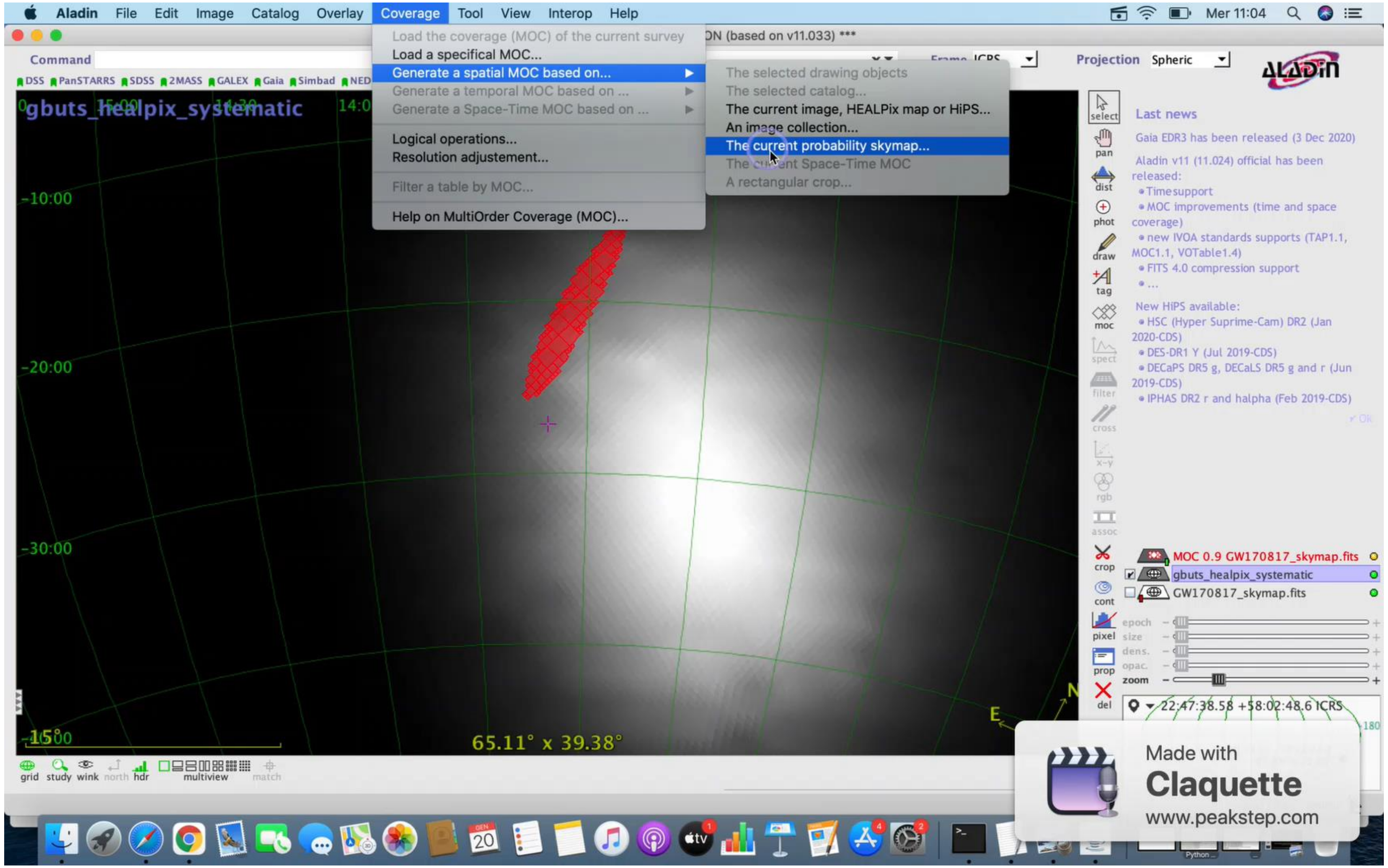
- Based on GWOSC: https://www.gw-openscience.org/about/

Findable

Accessible

Interoperable:
interoperability of data will be guaranteed through standard tools like the Virtual Observatory. Specific actions on these aspects are already starting thanks to the support of European projects like ESCAPE and AHEAD2020.



Q05: FAIRness of ET data

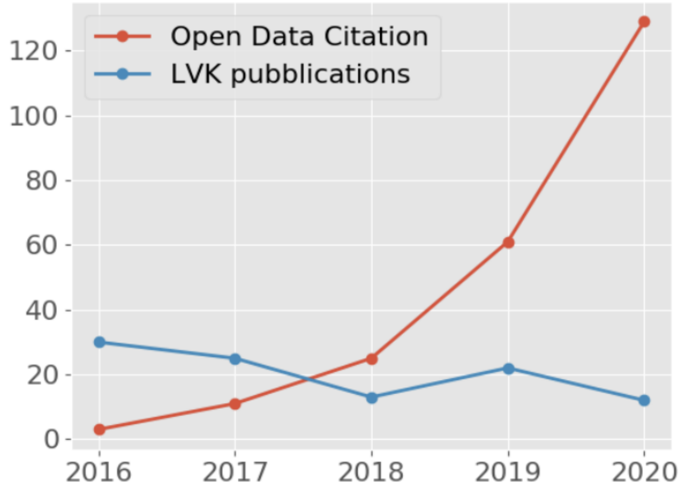
- Based on GWOSC: https://www.gw-openscience.org/about/

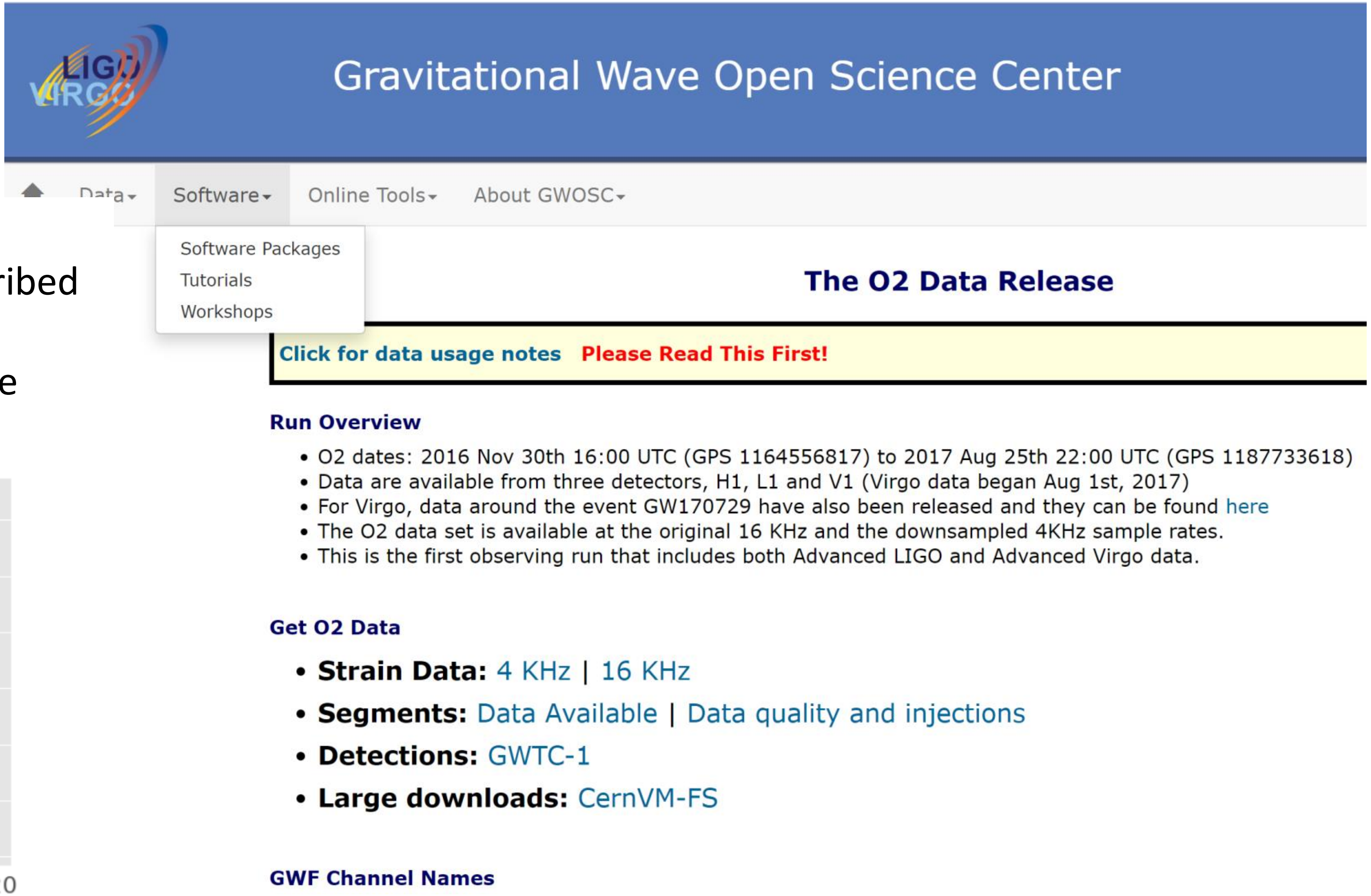
Findable

Accessible

Interoperable

Reusable:
data and metadata will be described and, thanks to the GWOSC and Virtual Observatory tools, will be easily reused





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Question 6

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What is the “secondment programme” referenced in the proposal and how will it be granted?

Q06: ET “secondment” plan

- The ET site will host an **excellence centre** in GW research
  - @ the site: competences in optics, lasers, vacuum and cryo technologies, electronics, mechanics, control systems, data handling and analysis, computing.
- The **analysis of the data** produced by ET needs competences in astrophysics, fundamental physics, material science, geophysics.
- The ET site will be an **attractor for scientists** in Europe and worldwide.
  - It is too early to define in detail the secondment programme that will be implemented in ET, but we can get an idea of it by looking at the programmes implemented at EGO, considering them as precursors of what ET can do.

Q06: what we mean with “secondment”

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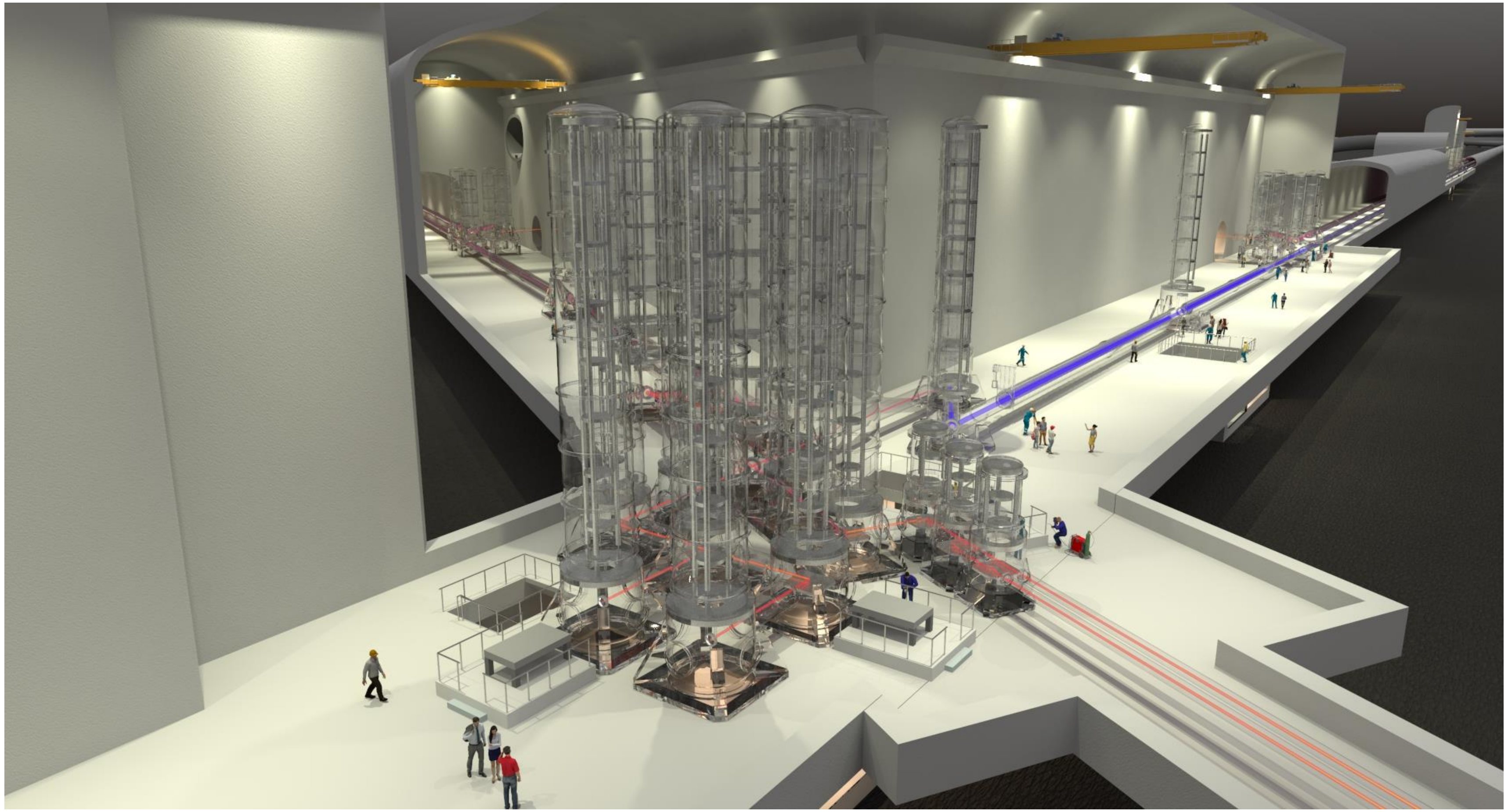
- A **fellowship programme** mainly (but not only) focused on the R.I. attracting young scientists engaged in different parts of the scientific and technical activities on site.
  - EGO example: This programme in EGO is based on its ordinary budget and it is functional to the success of the Virgo project.
  - In ET, it can be complemented by a secondment programme, perhaps benefiting from ET's possible ERIC legal status, also attracting senior scientists.
- A **transnational access programme** based on competitive funds (the successor of H2020 and Horizon Europe)
  - In EGO secondment programmes and access possibilities have been also implemented through specific I3 initiatives within FP7 and H2020.
  - In ET we plan to intensively pursue this possibility, applying to the European and International competitive calls available in the future.

Question 7

Please provide details of the

- strategy for funding the preparatory (Q7a) and
- implementation (construction) phases (Q7b) and further clarification on the
- procedures and timeline associated with the decision for final location of the ET (Q7c)



Q7a Strategy for funding the Preparatory phase

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Preparatory phase funding of the project and technology development are well underway

Preparatory phase budget

- M€ 171 for 2019 to 2030

More than M€ 70 already granted

- Italy: about M€ 35
- Euregio Meuse-Rhine: about M€ 35
- AdV+ investments

Site dependent items: M€ 60 needed from 2024 onward

- RI Technical documentation: M€ 38
- Land acquisition: M€ 19
- Detector project completion & site comparison: M€ 3

Technology development until 2030: M€ 41

- Horizon Europe contribution (modest)
- Several countries are expected to co-finance, but only after ET appears on ESFRI Roadmap

Activity	Cost [M€]	Start	End	Note
Site Qualification	15	2019	2023	Complex series of activities, going in parallel in the two candidate sites, aiming to the qualification of the sites (compliance with the stringent ET requirements).
Funding schemes for the two sites	0	2019	2023	Definition of the two funding schemes for the two candidate sites. Interaction and negotiation between countries.
Site Comparison	1	2023	2024	Evaluation of the two candidatures, using also external panels, experts and companies.
RI Technical documentation completion	38	2024	2026	Completion of the technical documentation needed for the construction (legally defined as preliminary project, definitive and operative project) by specialised external companies.
Governance definition -ERIC	1	2020	2025	Study and definition of the governance structure of ET.
Land acquisition	19	2024	2027	Acquisition of the land for the excavation and for the realisation of the surface infrastructures.
Technology development	95	2019	2030	R&D activity addressed to the development of the technologies needed for ET. This activity is already started since years and it is partially based on the technology developed for the upgrades of the current detectors.
Detector project completion	2	2023	2026	Completion of the detector project after the selection of the site.
Tot	171			

Table from Cost-book submitted to ESFRI

Q7b Strategy for funding the Implementation phase

ESFRI acknowledgement of scientific excellence of Einstein Telescope, the intrinsic value, the urgency, and of the significance for scientific leadership for Europe is of paramount importance

Underground infrastructure

- M€ 932 excavation, civil and services for 2026 to 2033
- National and/or regional funding
- Substantial contribution provided by host(s)

Vacuum system

- M€ 566 for 2026 to 2032
- Provided as national and/or regional funding, and/or common fund contributions from agencies/institutes

Detector

- M€ 238 for 2026 to 2035
- Agency/institutes/national funding schemes

Activity	Cost [M€]	Start	End	Note
Infrastructure costs	932			
Excavation	781	2027	2033	Excavation of the underground tunnels with TBMs and of the caverns. Cost based on the evaluation by two independent external companies.
Direction of the civil works	9	2026	2034	Evaluation based on the 1% of the underground and surface infrastructures realisation cost.
Civil works on the surface	98	2028	2033	Realisation of the technical and civil infrastructures on the surface. Cost evaluation based on the Conceptual Design study.
Services underground (ventilation ...)	44	2030	2033	Technical infrastructures serving the underground facilities and apparatuses.
Detector costs	804			
Vacuum system	566	2026	2032	Vacuum plant, pumps and pipes.
Optics and Laser	125	2027	2032	Main mirrors, auxiliary optics and lasers.
Suspension system	48	2027	2032	Filtering and suspension systems.
Cryogenics	45	2026	2032	Cryogenic plants.
ET installation	20	2032	2035	Contracts and activities for the installation of the ET components.
Total	1736			

Table from Cost-book submitted to ESFRI

Cost side of the project is clear, but at this time in the process it is premature to give full clarity on the financial backing of all stakeholders

Participating Ministries will decide on site selection (2024) and on sharing of the cost

Q7c Site decision timeline and procedure

Activities are well underway. Decision and site selection procedure determined at government level

Site qualification activities in progress

- In parallel at two sites: Sardinia and Euregio Meuse-Rhine
- Working groups as part of the Instrument Science Board
- Site Preparation Board instituted to oversee the process of *e.g.* site information, data analysis
- External parties (companies): construction, budget, socio-economic aspects
- Cost of civil infrastructure will be site dependent

Risk assessment

- More than 85% of the implementation budget is in infrastructure and vacuum system
  - Vacuum system is relatively low risk
  - Infrastructure relatively modest risk (globally > 5,000 km of tunnel/year; we can select the location), and significant de-risking is ongoing (Early Contractor Involvement)

Site selection procedure in Preparatory phase

- Decision and site selection procedure will be determined at government level
- See answers to Q10

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Question 8

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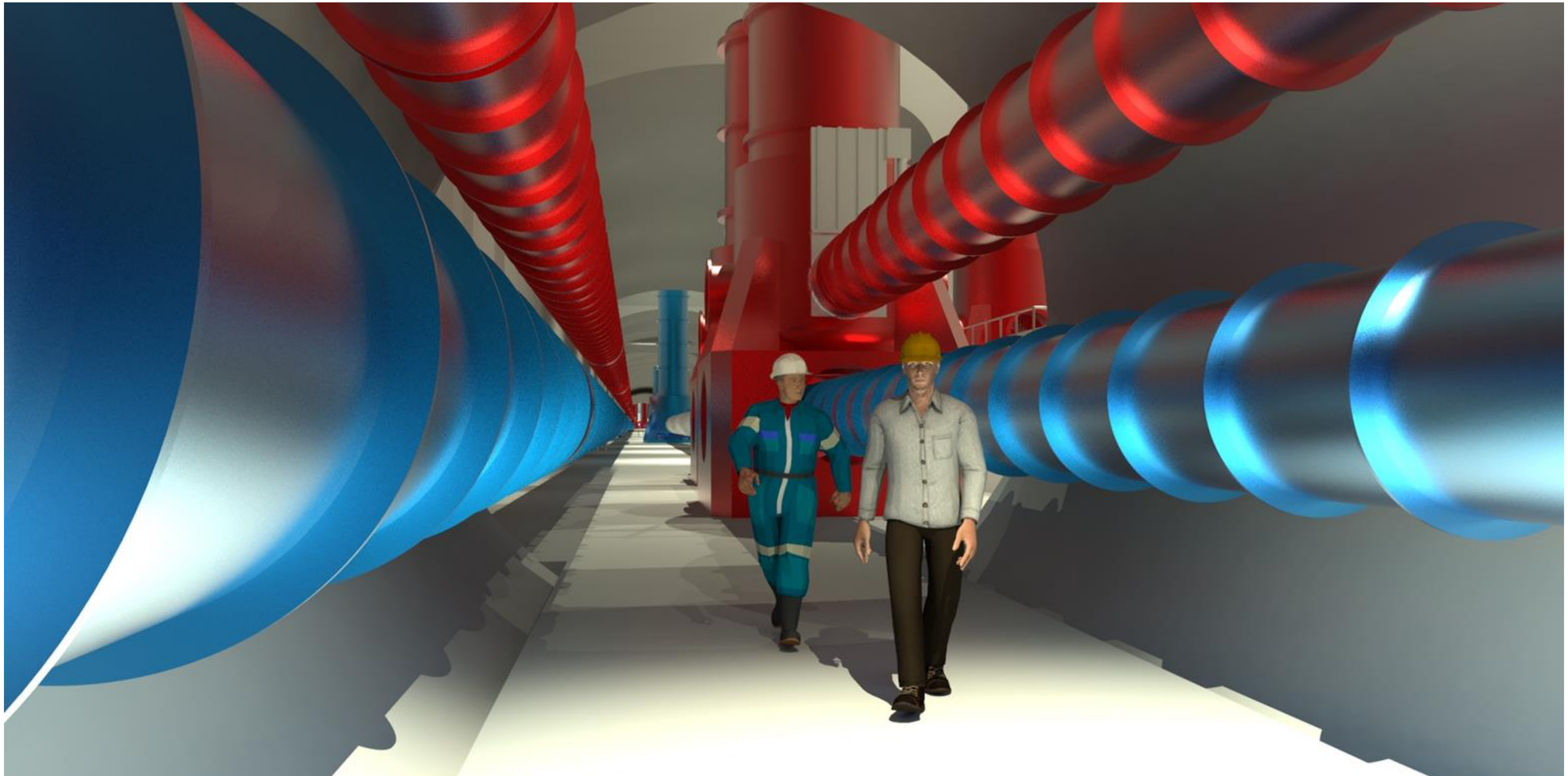
What approaches will be taken to
- increase the number of participating countries (Q8a) and ultimately
- broaden the membership (Q8b) over the coming years?



Q8a Increase the number of participating countries

Strategy in place for increasing the number of participating countries and ultimately broaden the membership over the coming years

Strategy

- Consortium Agreement already signed by institutes from 11 European countries
- Stimulate communities of GW-scientists in different countries to turn to their Ministries
- Ministries will listen to their national communities, but need an independent assessment
- ESFRI is a blue ribbon panel that can provide such a stamp of scientific excellence
- Next step (see section 9.1 of our proposal) is for Coordinators to set up an Interim Council

Significant progress in increasing the number of participating countries: examples

- France
  - IN2P3 brings its support to ET application for ESFRI roadmap and it is tasked to update French Ministry of Research on the project
  - ET should be mentioned - for the first time - in the landscape of the 2021 national roadmap for large research infrastructures
  - First workshop in France on ET showed massive interest (February 4, 2021)
  - Infrastructure of strategic importance (*e.g.* unique mirror coating at Laboratoire des Matériaux Avancés)
- Germany
  - Federal Ministry of Education and Research BMBF provided seed funding to fourteen German universities and research institutions for work on GW research
  - State of North Rhine-Westphalia gave unanimous approval to actively support the process of realizing ET (November 11, 2020) in Euregio Meuse-Rhine. Partners in E-TEST and ETpathfinder project (30 M€)

Back-up slides for details on relevant developments in various countries are available

Q8b Broaden membership: Virgo as gateway to ET

Virgo has more that doubled its size in the last few years. Virgo is a European collaboration with 678 members, 447 authors from 124 institutions

Virgo is a 2nd generation GW detector in Europe, while ET will be the next step

- EGO Council composed of France, Italy and the Netherlands
- Participation by scientists from Belgium, China, Czechia, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Monaco, Poland, Portugal, Spain, The Netherlands

Gravitational wave science: steep learning curve

- Join gravitational wave science
- Learn about instrumentation and data analysis
- Path to third generation: Einstein Telescope
- Many members traditionally from CERN community

Virgo as gateway to Einstein Telescope

- Quantum technologies: frequency dependent squeezing
- Large test masses and advanced coatings

13 European countries

Q8b Broaden membership: ET serves other communities

ET provides data for fundamental physics, astronomy, astrophysics, nuclear physics and cosmology

Multi-messenger science involves large and global collaboration of scientists

- Correlate high statistics GW data with other (*e.g.* EM) observations (SKA, Vera Rubin, CTA, …)
- ET will be one of the ultimate instruments to realize multi-messenger exploration of the Universe
- ET's Observational Science Board has members from other communities

The Astrophysical Journal Letters, 848:L12 (59pp), 2017 October 20 https://doi.org/10.3847/2041-8213/aa91c9

Multi-messenger Observations of a Binary Neutron Star Merger

LIGO Scientific Collaboration and Virgo Collaboration, Fermi GBM, INTEGRAL, IceCube Collaboration, AstroSat Cadmium Zinc Telluride Imager Team, IPN Collaboration, The Insight-Hxmt Collaboration, ANTARES Collaboration, The Swift Collaboration, AGILE Team, The 1M2H Team, The Dark Energy Camera GW-EM Collaboration and the DES Collaboration, The DLT40 Collaboration, GRAWITA: GRAvitational Wave Inaf TeAm, The Fermi Large Area Telescope Collaboration, ATCA: Australia Telescope Compact Array, ASKAP: Australian SKA Pathfinder, Las Cumbres Observatory Group, OzGrav, DWF (Deeper, Wider, Faster Program), AST3, and CAASTRO Collaborations, The VINROUGE Collaboration, MASTER Collaboration, J-GEM, GROWTH, JAGWAR, Caltech-NRAO, TTU-NRAO, and NuSTAR Collaborations, Pan-STARRS, The MAXI Team, TZAC Consortium, KU Collaboration, Nordic Optical Telescope, ePESSTO, GROND, Texas Tech University, SALT Group, TOROS: Transient Robotic Observatory of the South Collaboration, The BOOTES Collaboration, MWA: Murchison Widefield Array, The CALET Collaboration, IKI-GW Follow-up Collaboration, H.E.S.S. Collaboration, LOFAR Collaboration, LWA: L…
Collaboration, ALMA Collaboration, Euro VLBI Team, Pi of the Sky …
Desert Fireball Network, ATLAS, High Time Resolution Universe Su…
(See the end matter for the full list of authors.)

3542 authors from 1008 institutes

Received 2017 October 3; revised 2017 October 6; accepted 2017 October 6; published 2017 October 16

Abstract

On 2017 August 17 a binary neutron star coalescence candidate (later designated GW170817) with merger time 12:41:04 UTC was observed through gravitational waves by the Advanced LIGO and Advanced Virgo detectors. The *Fermi* Gamma-ray Burst Monitor independently detected a gamma-ray burst (GRB 170817A) with a time delay of $\sim$1.7 s with respect to the merger time. From the gravitational-wave signal, the source was initially localized to a sky region of 31 deg^2 at a luminosity distance of 40^{+8}_{-8} Mpc and with component masses consistent with neutron stars. The component masses were later measured to be in the range 0.86 to 2.26 $M_{\odot}$. An extensive observing campaign was launched across the electromagnetic spectrum leading to the discovery of a bright optical transient (SSS17a, now with

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Question 9

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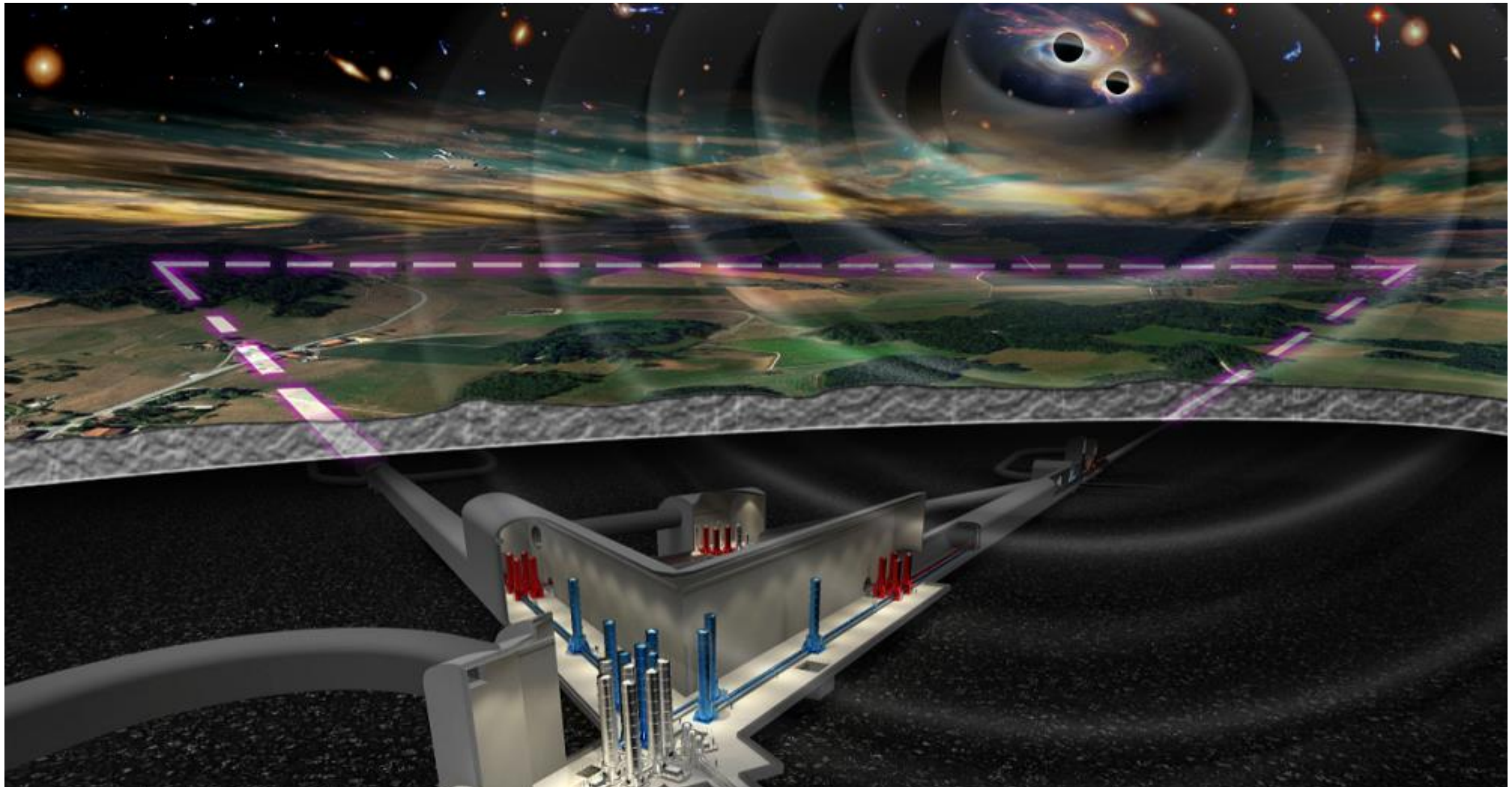
Please provide further details on the

- business plan (Q9a) and on the
- timeline (Q9b) for the ET.

Include in your response the

- agreed steps for their final approval and sign-off (Q9c) by the Consortium and Board



Q9a Business plan

Business case is part of Preparatory phase

The business case required by participating Ministries encompasses items like

- stakeholders engagement: financial plan, governance
- management: risk, data, communication, outreach, …
- gender/minorities balance
- scientific value creation in various fields: joint EU scientific collaborative effort

Business case will be worked out into a solid business plan

- in the next years the business plan (of which a.o. a financial plan is an integral part) will be developed and this is also important to convince new partners that Einstein Telescope has a solid plan

Business plan will include benefits realisation and other impact (more on next slides)

- Technology value and innovation, industry, spin-out
- Socio-economic value and regional development

Examples of added value of Einstein Telescope

- Value creation for society
- Value creation with European industry

Q9a1 Value creation for society

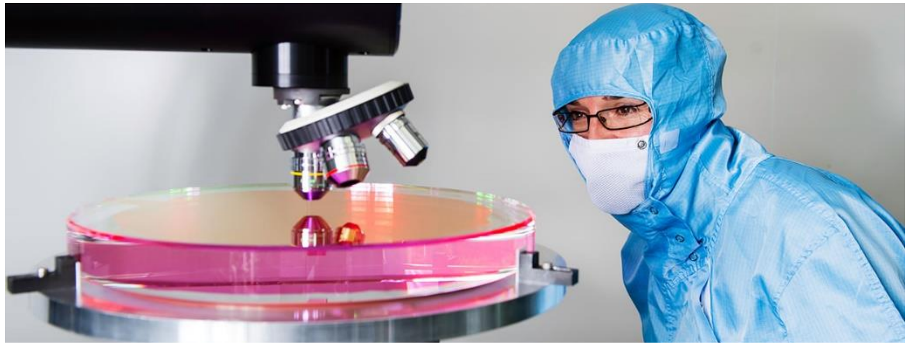
ET stimulates national and regional innovation power, activity, employment and attractivity for top scientists

Socio-economic studies

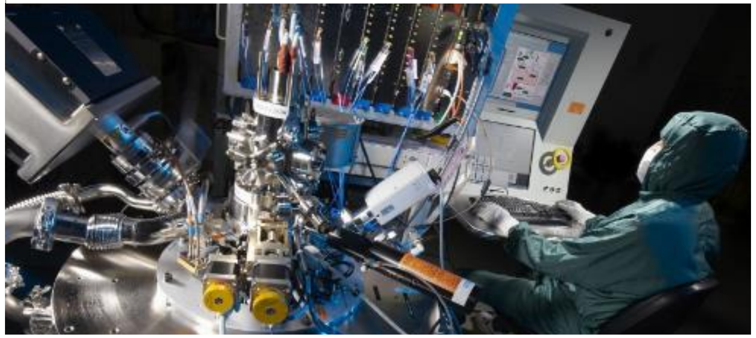
- employment: 34,000 man-years during construction; 1,500 jobs structurally
- each euro invested provides a total of 3.6 euros in the economy

Measuring and attenuating vibrations: nano-technology, medical, defense

Optics: coatings, special materials, laser technology, semiconductor technology



Cryogenic systems: ET's low frequency interferometer will feature cooled silicon optics



Vacuum technology: ET will feature one of the biggest vacuum systems worldwide

ET UHV system:
- beam tubes: 120,000 m^3
- pressure < 10^{-10} hPa
- hydrocarbons < 10^{-14} hPa
- area: 420,000 m^2

LHC at CERN:
- beam tubes: 2,000 m^3
- pressure < 10^{-10} hPa
- insulating vac.: 15,000 m^3
- pressure < 10^{-6} hPa

Q9a2 Value creation with industry

CERN-GW development program to identify materials and coatings that lead to minimal outgassing, whereby –to save cost– the bake-out of the UHV system can be avoided as much as possible

CERN

MOU in place between CERN and ET Coordinators (INFN and Nikhef)
Head of CERN's Vacuum Department serves as co-chair on ET's Pipe Arm Vacuum WG
Confirmed findings of Park *et al.*, on mild steel

Einstein Telescope

Nikhef, RWTH Aachen, Fraunhofer IPT, INFN-Rome: Test facilities

Tata Steel

Producer of high purity low carbon steel, coatings
Vacuum treatment to de-hydronize liquid steel at 1600^{o}C

VDL Group

International industrial and manufacturing company
Translate laboratory results to production processes on the scale required for ET

Connections to other innovative activities

Hydrogen economy, Hyperloop project, fuel cells, …
Pursue joint collaboration with Cosmic Explorer, the 3G project in USA

Q9b Project timeline

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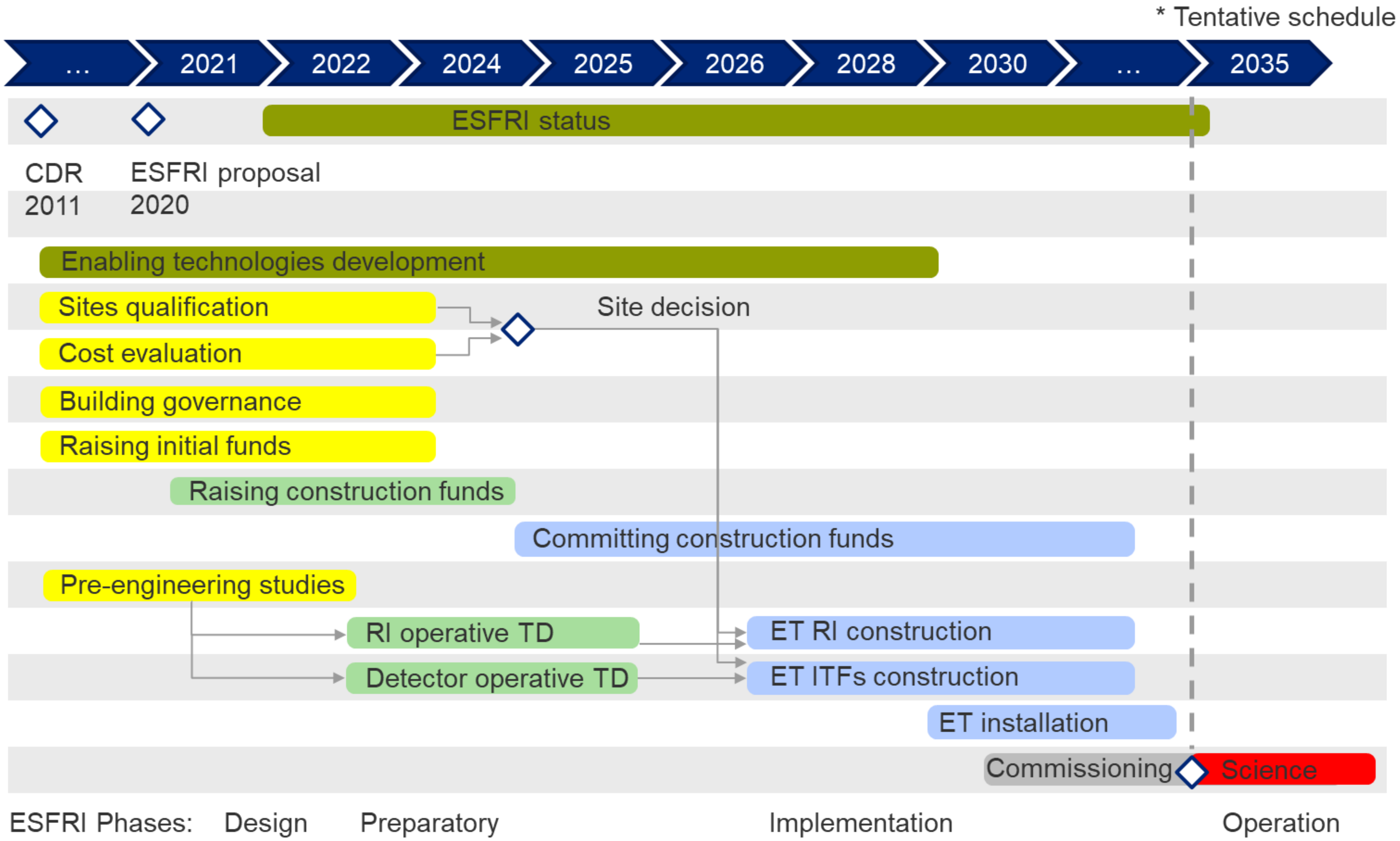

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Q9c agreed steps for their final approval and sign-off

EINSTEIN TELESCOPE

Group of participating Ministries will decide about site selection and organisation

Coordinators

- Implemented a Project Directorate (see answers to Question 10)
- Setting-up an Interim Council by participating Ministries hopefully in early 2022

(Interim) Council

- Appointment of
  - Ad-hoc Committee on Governance
  - Scientific and Technical Advisory Committee
- Site selection, budget (national and regional)
- Legal entity creation and structure of project-organisation

Project Directorate: agreed steps for future approval and sign-off by Council

- Solid and sustainable Einstein Telescope organisation
  - Monitoring, stimulating and developing an effective interface between project organisation and the scientific community
  - Control time schedules, priorities, and budgetary constraints
- Manage site qualification, risk and cost, socio-economic impact
- Technology development for infrastructure and vacuum

Coordinators

Antonio Zoccoli, INFN
Stan Bentvelsen, Nikhef

Project Directorate

Fernando Ferroni, INFN
Jo van den Brand, Nikhef

Question 10

ESFRI considers that insufficient

– plans at this stage have been put in place to address governance related matters (Q10a)

Please provide further information to satisfactorily address the necessary

– minimal key requirements related to governance (Q10b)

Q10a Progress since proposal submission

A broad ET community (represented in the organogram below)

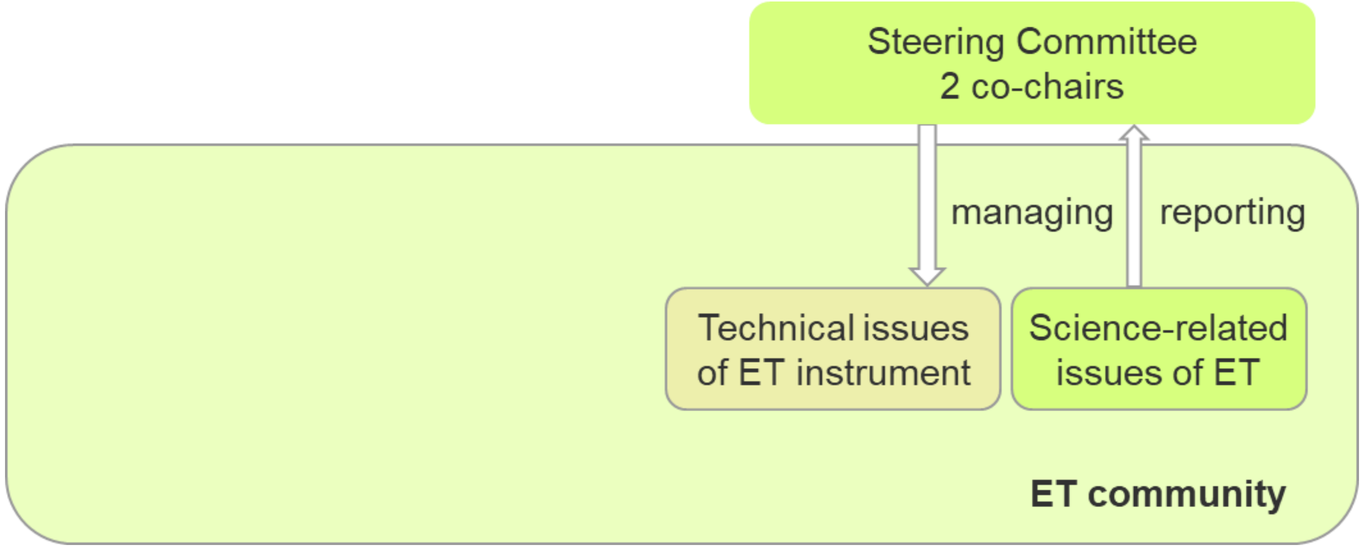
See contribution by Michele Punturo

Successful realization of ET needs a concerted professional effort from all angles

- Ministries, research organizations and scientific community
- Impose a long-term governance structure within the framework of the phases of the ESFRI Life-cycle approach

Goals for 2021/2022: implement the Project management and governance

- Now: establish the governance for the Preparatory phase
- Construction phase: being defined
- Exploitation phase: under consideration



Q10a toward governance in Preparation phase

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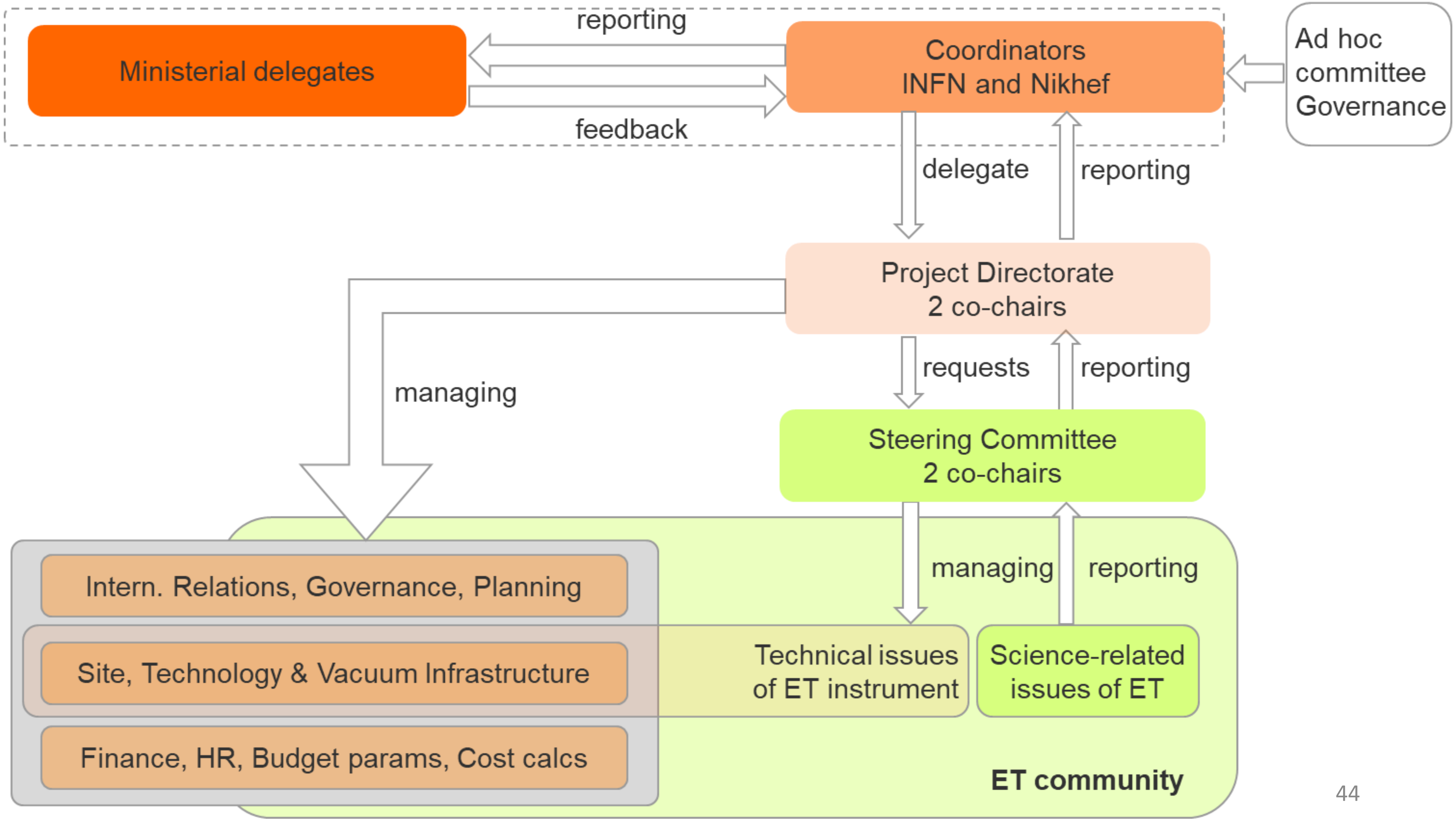
Structure implemented by agencies: an interim structure for the ET project organization until establishment of a Council



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Q10b toward governance in Construction phase

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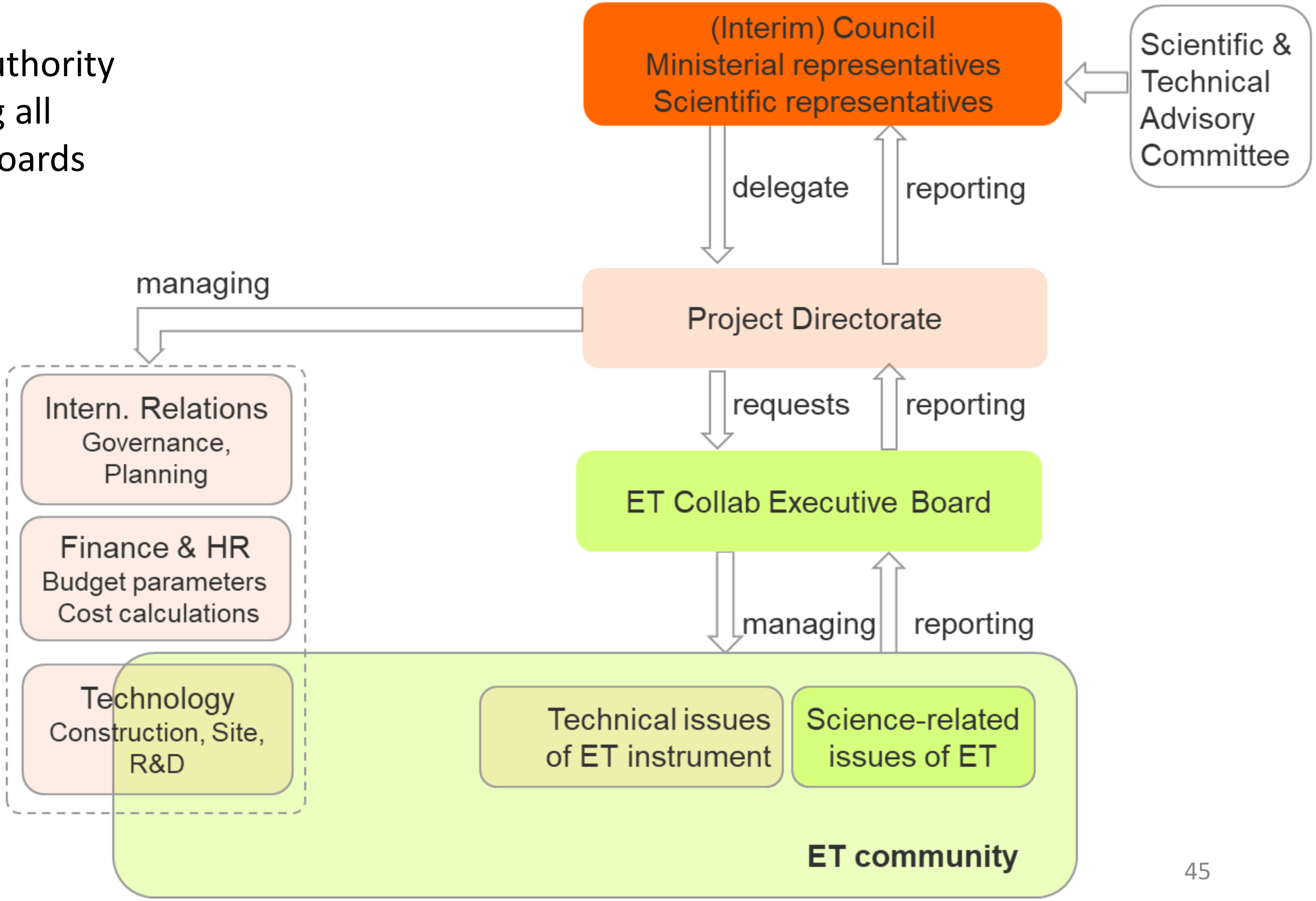
Structure after ESFRI approval

Interim Council
evolves into Council: the highest authority in the organization accommodating all countries and assisted by various boards

Project Directorate
may evolve into ET Directorate

Council appoints DG, and directors for Finance & HR, Technology, Science & Computing, International Relations, …



Q10b proposal for governance in Construction phase

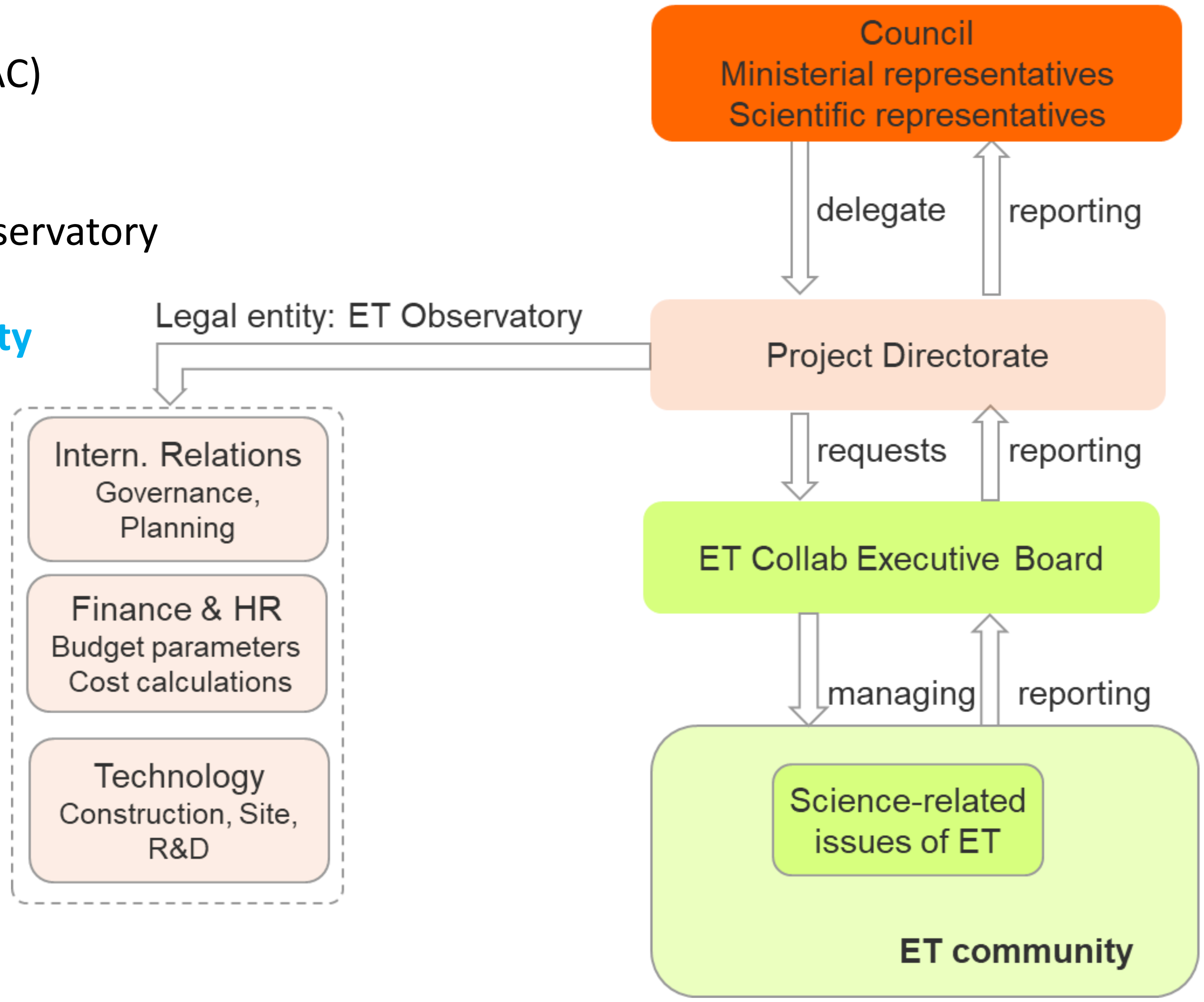
Structure during Implementation phase

Council
Assisted by several bodies (*e.g.* STAC)

Project Directorate
evolves into Einstein Telescope Observatory

ET Observatory will be a legal entity
and will have significant staff

Verify by expert panel on governance and project organization



Summary

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Einstein Telescope has a high discovery potential, remarkably precise measurement capabilities and highest scientific yield. It is timely and important for Europe

- Unique approach to directly study the early Universe in gravitational waves
- Precision studies of compact objects: black holes and neutron stars
- Invaluable data for fundamental physics, astronomy, astrophysics, nuclear physics and cosmology

Interest in gravitational-wave science and in Einstein Telescope is growing in Europe

- GW science appears prominently on APPEC, Astronet as well as on various national roadmaps
- ET's scientific and technological output will boost knowledge and innovations in many sectors

Governance, management, budget and risk

- Recent actions to professionalise governance and to map the evolution toward the Project phase
- Initial budget estimates were made with professional input
  - About 85% of the budget is in underground construction and vacuum system: relatively low to modest risk
  - These underground construction and vacuum related engineering activities have well established management practices
  - Detector instrumentation (15% of the budget) is in the hands of physicists and engineers that created LIGO and Virgo

Europe plays a leading role in the current scenario of gravitational wave research

- ET promises to strengthen this position as the most advanced 3G GW observation project
- ET needs a pan-European effort and coordination and only inclusion in the ESFRI Roadmap can promote gathering European countries around this unique project
- The project is timely and will allow to keep the European leadership in 3G

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References

- [1] Di Giovanni, Matteo et al, “A Seismological Study of the Sos Enattos Area-the Sardinia Candidate Site for the Einstein Telescope”, DOI: 10.1785/0220200186
- [2] Tomislav Andric, Jan Harms, “Simulations of Gravitoelastic Correlations for the Sardinian Candidate Site of the Einstein Telescope”, DOI 10.1029/2020JB020401
- [3] ATLAS HL-LHC Computing Conceptual Design Report: http://cds.cern.ch/record/2729668/files/LHCC-G-178.pdf?version=2
- [4] E. Cuoco et al., “Enhancing Gravitational-Wave Science with Machine Learning”, https://arxiv.org/abs/2005.03745
- [5] D. George et al, “Deep Learning for Real-time Gravitational Wave Detection and Parameter Estimation: Results with Advanced LIGO Data”, https://arxiv.org/pdf/1711.03121.pdf

Back-up slides

Developments in various countries

Gravitational Wave International Committee GWIC

Gravitational Wave Agency Correspondents GWAC

Q1-Q6 Spare slides

Italy and the Netherlands

Expressions of political and already commitment to significant financial support

Italian Ministry of Universities and Research

- Commitment to support ET project in Implementation and Operation phases
- Fund accordingly the project through its **national and regional funds**
- Provided that the **financial responsibilities of the hosting country will be further defined** and clarified in the Preparatory phase or in the subsequent pre-Implementation phase
- Italian Infrastructure Roadmap PNIR in progress

Dutch Ministry of Education, Culture and Science

- Support the proposal to include the Einstein Telescope for inclusion in the 2021 ESFRI Roadmap
- On the National Roadmap for Large-scale Scientific Infrastructures of the Netherlands since 2018
- Before the construction phase, a **selection procedure should be drawn up** by the countries likely to invest in Einstein Telescope. Calls for **transparent bidding process** with clear terms of reference for evaluating proposals
- Countries involved should agree an **interim governing mechanism** for making decisions such as site selection, made up of ministerial and scientific delegates from the respective countries
- Site selection should be finalized in 2025 so as not to delay the start of operations in 2035
- Netherlands joined Italy and France as full member of EGO

Investments

- Italy: investment of about M€ 35 already allocated
- Netherlands (with Belgium and Germany): joint investments of about M€ 35 already allocated

Belgium and Poland

Expressions of political and already commitment to significant financial support

Belgian Interministerial Conference for Science Policy

- More than ten Belgian research groups have joined forces to coherently contribute to the 3rd generation gravitational wave research program
- U-Antwerp, U-Gent, KU-Leuven, STAR-ULiège, UCL, ULB, VU-Brussel joined Virgo
- Einstein Telescope on the Flemish Roadmap for Research infrastructures: "Large scale research infrastructures in Flanders: Flemish participation in international research infrastructures 2020“
- Before starting the construction phase of the underground facility, the final **site will have to be selected following a clear and transparent procedure**, widely supported among the participating countries. We will support actively the creation of an **interim governance body** with all the participating countries to prepare the decision-making process and validate the proposed selection procedure

Polish Ministry of Science and Higher Education

- Supports ET application for ESFRI Roadmap 2021 inclusion
- National support but no financial commitment yet. In-kind contributions appealing
- AstroCeNT: new international centre of excellence in the field of particle astrophysics
- No less than 5 universities are now involved (also in site-characterization studies)

Spain

While no financial commitments yet, Spain is showing a growing involvement in GW and ET

Spanish Ministry of Science and Innovation

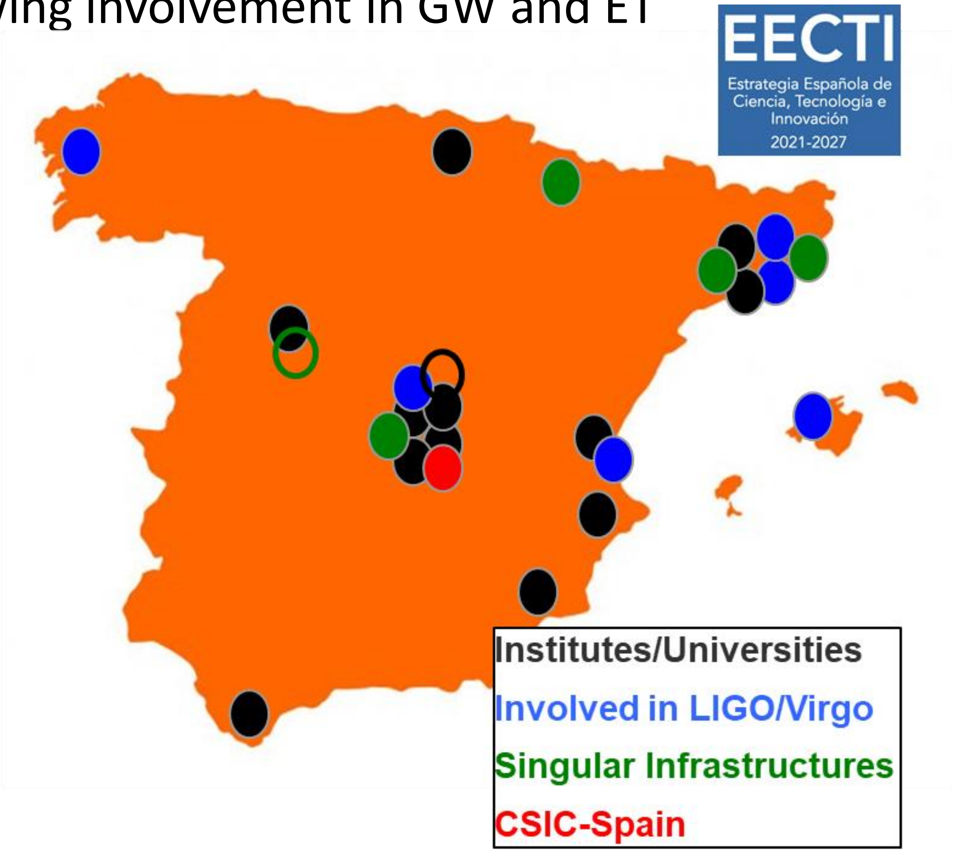
- Confirms support and political commitment to ET
- National support but no financial commitment yet

Growing tendency in Spain to support GW

- Letter of support for ET signed by 23 Spanish institutions, including the Spanish Research Council (CSIC) and "four singular infrastructures as the BSC-Super-Computing Center or the ALBA-Synchrotron in Barcelona" that can provide significant hardware/computing resources
- Other centers being recently contacted like the Laser Singular infrastructure in Salamanca or the Institute for Optics in Madrid
- The research on GWs has been included explicitly in the Spanish Strategic plan for Science, Technology and Innovation (EECTI) 2021-2027

After ESFRI approval GW community may request significant funding for Preparatory phase

- Community getting organized to act coherently



Besides Univ. Valencia also Barcelona Univ. and IFAE Barcelona joined Virgo in preparation of ET. Latest addition was Autonomous University of Madrid. Centers in LIGO and LISA also interested in ET

France

Strong commitment of French scientific community to gravitational-wave physics and ET

France and gravitational-wave physics: CNRS is a founding member of Virgo and of the European Gravitational Observatory and is currently strongly supporting Virgo operation and upgrades. France is also strongly involved in LISA and it counts theory groups strongly contributing to GW research (*i.e.* waveform developments)

ET at IN2P3 and CNRS

- IN2P3 brings its support to ET application for ESFRI roadmap and it is tasked to update French Ministry of Research on the project
  - Letter of intent of IN2P3 to support ET ESFRI application (August 7, 2020)
  - IN2P3 Scientific Council recommended the Einstein Telescope project (October 2020)
  - Participation to ET activities is well established at IN2P3 and is growing well beyond IN2P3
  - ET is well established in the 2020-2030 IN2P3 roadmap exercise
- ET should be mentioned - for the first time - in the landscape of the 2021 national roadmap for large research infrastructures
- ESFRI approval will accelerate funding requests, *e.g.* for technology development

Gravitational wave science

- First workshop in France on Einstein Telescope showed massive interest (February 4, 2021)
- French scientists are well represented in ET Collaboration boards
  - Instrument Science Board, Observational Science Board, e-infrastructure Board

Infrastructure of strategic importance in France

- LMA: only laboratory in the world capable of providing the coatings required for GW detectors
  - CNRS is investing heavily in LMA (Laboratoire des Matériaux Avancés, Lyon)
- CC-IN2P3: computing centre for Virgo/LIGO data-analysis

Germany

Strong community effort is building up in Germany

BMBF Federal Ministry of Education and Research

July 20, 2020: the Federal Ministry of Education and Research provided 2.1 M€ to fourteen German universities and research institutions for work on various technological aspects of GW research

- BMBF does not support ET financially, but it is funding gravitational wave physics (and the results might contribute to ET development)
- Activities include seismic measurements and developing crystalline fibers for the support of the large mirrors
- It is the first time in 30 years that BMBF supports gravitational wave physics on such a high level

State of North Rhine-Westphalia

November 11, 2020: unanimous approval of NRW Parlament to instruct the NRW Government to

- actively support the process of realizing Einstein Telescope, through financial support for accompanying research projects by focusing on the regional and economic dimension of the project and by strengthening the cross-border and trilateral networking in favor of the project
- work together with the Netherlands and Belgium and support the Euregio Meuse-Rhine in its related activities

Involvement of Helmholtz Association, Fraunhofer- and Max Planck Society, and universities

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United Kingdom

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Developments since submission of the ESFRI proposal

UK Research and Innovation, UKRI

- Einstein Telescope designated as project of future interest
- Global governance of paramount importance
- ESFRI approval would accelerate the process

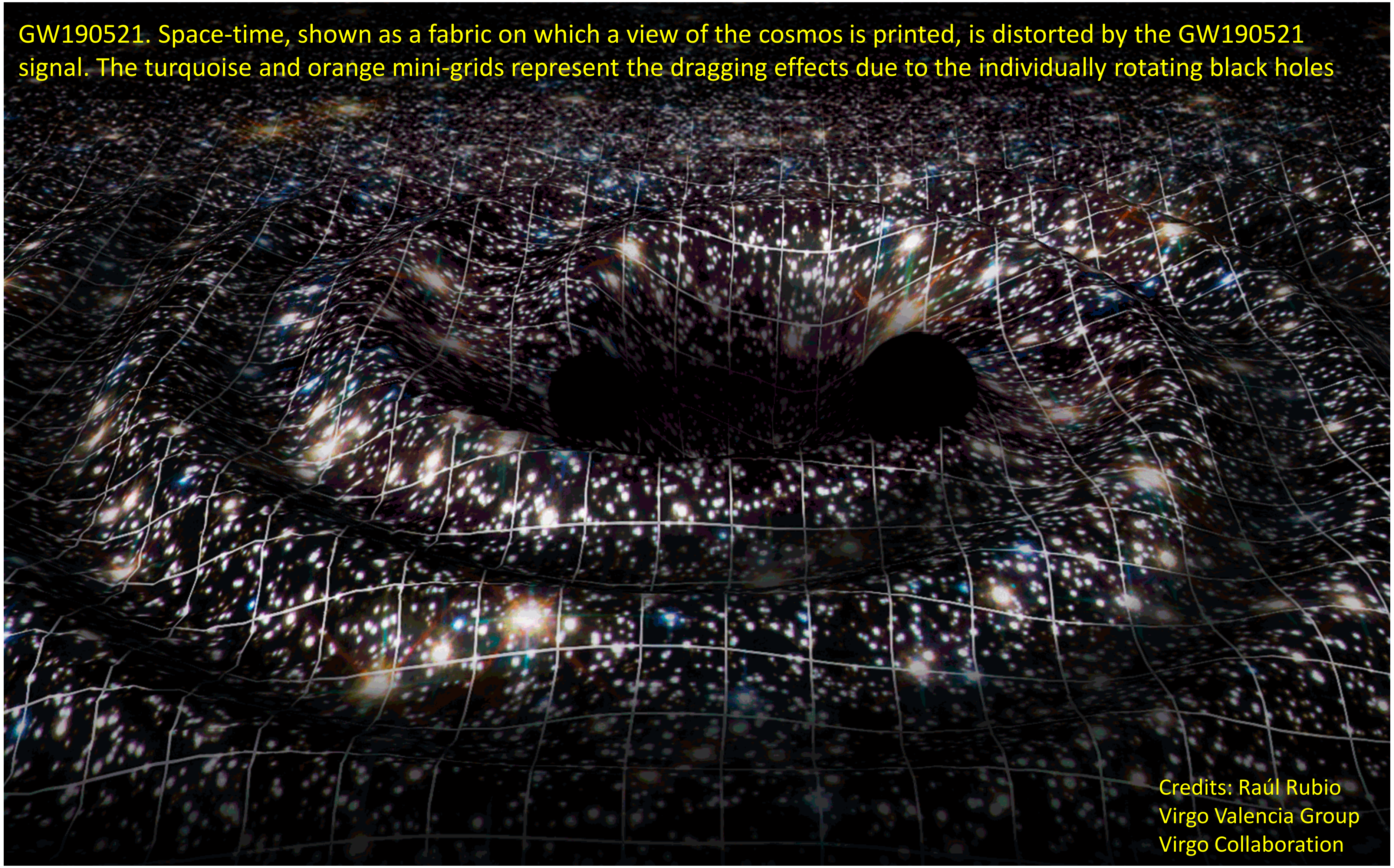
Gravitational wave science

- Long tradition in gravitational wave science: LIGO, GEO600
- Member of the group that initiated Einstein Telescope
- Support for Einstein Telescope
  - Institutional Memorandum of Agreement from Universities of Birmingham, Cardiff, Glasgow, Portsmouth and Strathclyde
  - Strong presence in Einstein Telescope's Instrument Science Board

Austria, Hungary, Switzerland, …

Many more discussions are underway

Global embedding



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Gravitational Wave International Committee

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Einstein Telescope is a project recognized by the IUPAP Gravitational Wave International Committee (GWIC) as a pillar in the next generation of ground-based gravitational wave observatories

What is GWIC?

- Working Group (GW11) of the International Union of Pure and Applied Physics (IUPAP)
- Links to the International Astronomical Union (IAU) and the International Society for General Relativity and Gravitation (ISGRG)
- GWIC membership represents the world's active gravitational wave projects, as well as other relevant communities, covering gravitational wave frequencies from nanohertz to kilohertz

GWIC on 3G GW observatories

- Established a 3G Subcommittee
- Promote international cooperation in construction and scientific exploitation of GW detectors
- Focus on 3G Detectors: Einstein Telescope & Cosmic Explorer

GWIC represents GW community internationally

- Interface to GWAC to provide a collective perspective on (European) work in the global context

GWIC 3G https://gwic.ligo.org/

Planning for a 3rd Generation Ground-based Gravitational-wave Observatory Network

Documents

3G Subcommittee Reports (September 2020)

The Next Generation Global Gravitational Wave Observatory: The Science Book
3G R&D: R&D for the Next Generation of Ground-based Gravitational-wave Detectors
GWIC 3G Community Networking Report
GWIC Governance Subcommitee Recommendations to Full 3G Committee
Gravitational-Wave Data Analysis Computing Challenges in the 3G Era

European Particle Physics Strategy Update 2018-2020 White Papers

Gravitational Waves in the European Strategy for Particle Physics

US Astro2020 Decadal Survey Science White Papers

Deeper, Wider, Sharper: Next-Generation Ground-Based Gravitational-Wave Observations of Binary Black Holes
The Yet-Unobserved GW Universe
Cosmology and the Early Universe
Extreme Gravity and Fundamental Physics
Multimessenger Universe with Gravitational Waves from Binaries
Gravitational Wave Astronomy with LIGO and Similar Detectors in the Next Decade
Gravitational-Wave Astronomy in the 2020s and Beyond: A View Across the Gravitational Wave Spectrum
The US Program in Ground-Cased Gravitational-Wave Science: Contribution from the LIGO Laboratory

US Astro2020 Decadal Survey Activity/Project White Paper

Cosmic Explorer: The U.S. Contribution to Gravitational-Wave Astronomy beyond LIGO

Report of the Dawn IV Workshop, held in Amsterdam, Netherlands, August 30-31, 2018

Global strategies for gravitational wave astronomy

Gravitational Wave Agency Correspondents

GWAC's primary purpose is to enable international co-sponsoring activities in GW Astrophysics

GWAC is a GW "funding" agencies committee promoted by NSF, involving

Australian Research Council (ARC)
Canada Foundation for Innovation (CFI)
Centre National de la Recherche Scientifique (CNRS)
Consejo Nacional de Ciencia y Tecnología (CONACYT)
Deutsche Forschungsgemeinschaft (DFG)
European Space Agency (ESA)
Indian Department of Atomic Energy (DAE)
Indian Department of Science and Technology (DST)
Istituto Nazionale di Fisica Nucleare (INFN)
National Aeronautics and Space Administration (NASA)
National Science Foundation (NSF)
Netherlands Organisation for Scientific Research (NWO)
Research Foundation - Flanders (FWO)
Science & Technology Facilities Council (STFC)

GWAC's main purpose is to create a direct channel of communication between funding agencies to coordinate the use of existing and explore new funding opportunities for the gravitational wave science community

https://www.nsf.gov/mps/phy/gwac.jsp

GWAC is a tool for the GW community. Type of activities

Large scale: developing new GW observatories

Medium scale: support of GW R&D of any kind (risk mitigation, characterization, DA, *etc.*)

Small scale: training of junior scientists, investigator exchange programs, *etc.*

Q1-Q6 Spare Slides

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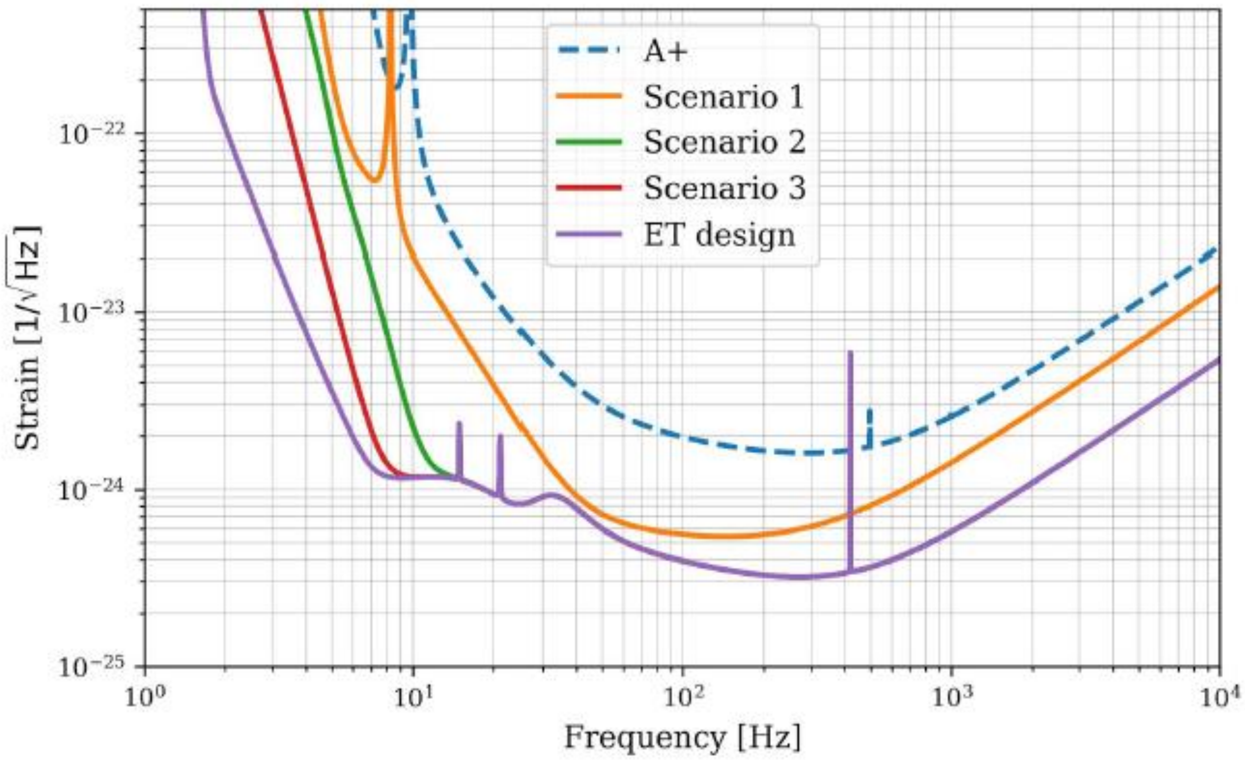
Q1: Evolution scenarios

ET EINSTEIN TELESCOPE

- Based on the experience achieved in Initial and Advanced detectors, we can depict 3 evolutionary scenarios, related to the technological challenges mentioned before, where the ET sensitivity is (temporarily) degraded:
  - A risk table has been evaluated wrt these 3 scenarios

Einstein Telescope



- Scenario1:
  - High power + squeezing issues affecting ET-HF performance
  - ET-LF missing
- Scenario 2:
  - ET-HF full sensitivity
  - ET-LF affected by severe noise issues
- Scenario 3:
  - ET-HF full sensitivity
  - ET-LF affected by some noise issues

Q1: Science Impact

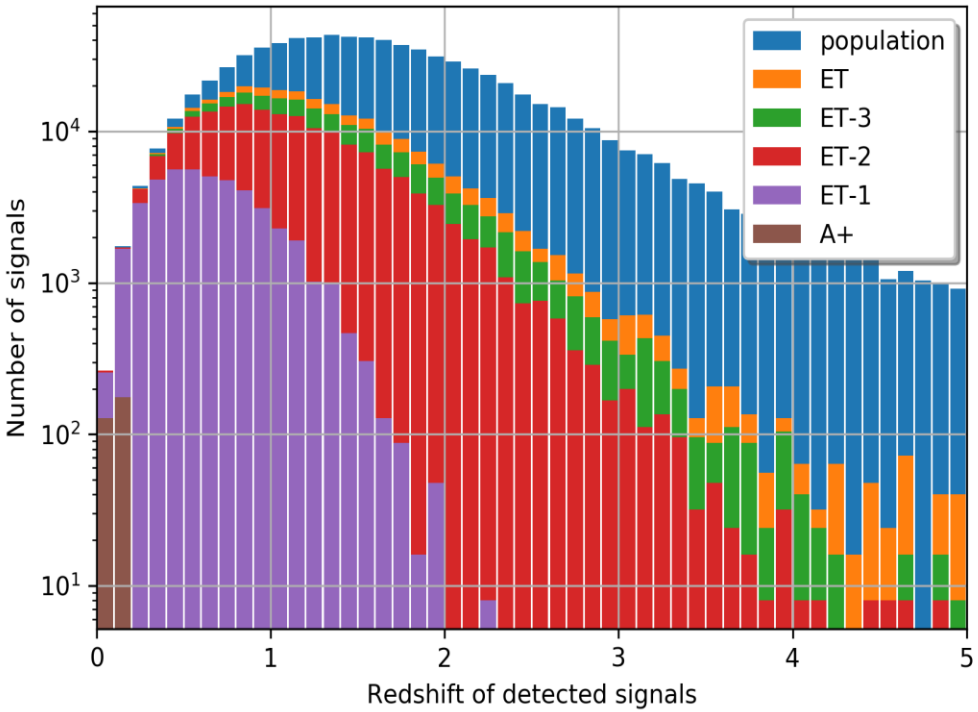
We evaluate:

- the impact of the three ET scenarios up to the ET design on the detection efficiency and sky-localization capabilities, focusing on a binary neutron stars (BNSs) and binary black holes (BBHs);
- the impact on achievements related to population studies, cosmology, test GR, intermediate mass black-hole (IMBHs) and primordial black-hole (PBHs) science;

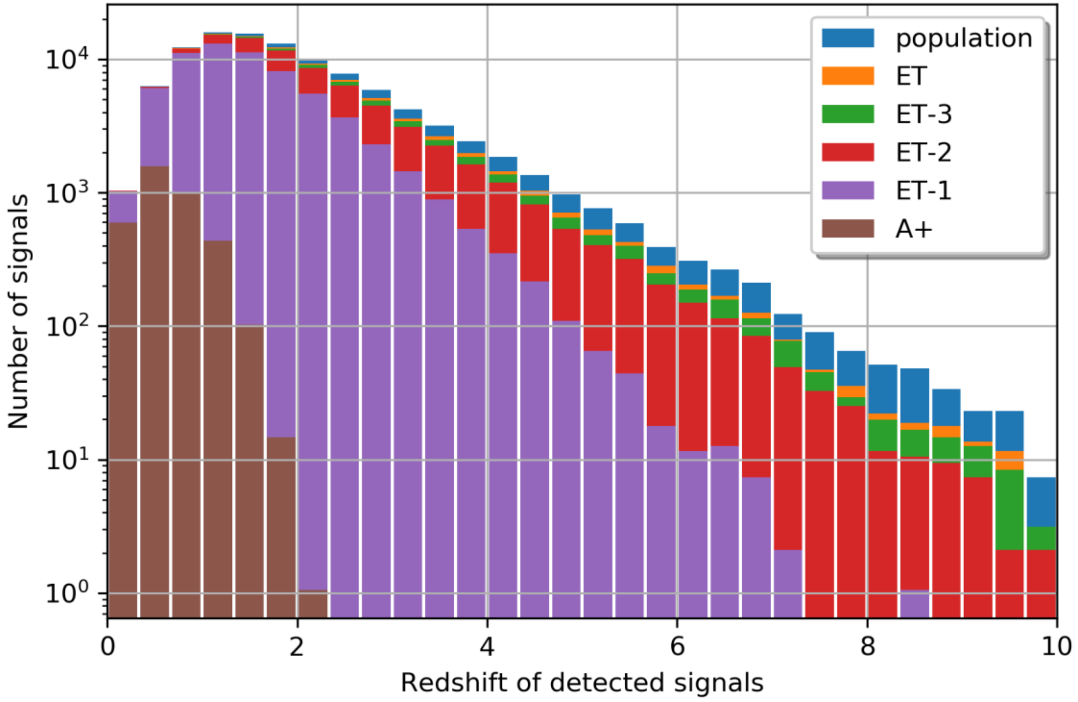
Q1: Science Impact

COMPACT OBJECT BINARY POPULATIONS

BINARY NEUTRON-STAR MERGERS



BINARY BLACK-HOLE MERGERS



Sampling **astrophysical populations** of binary system of compact objects along the cosmic history of the Universe

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Q1: science Impact

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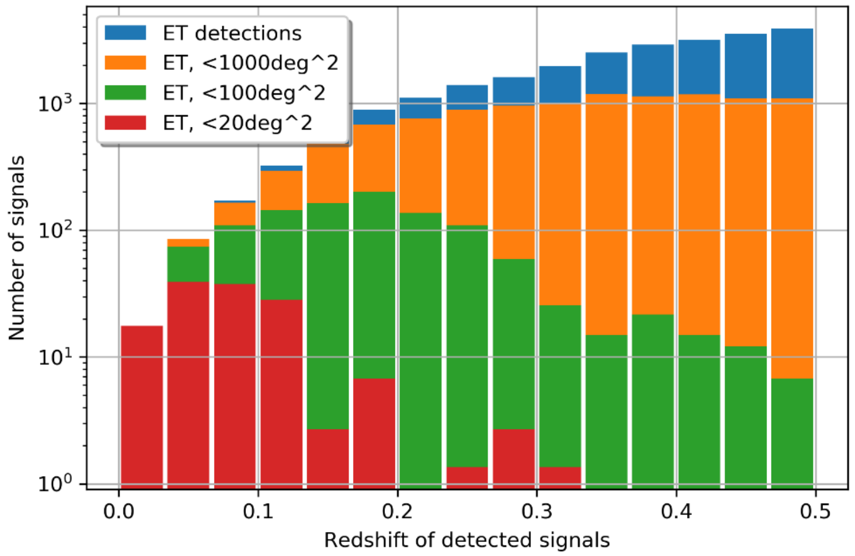
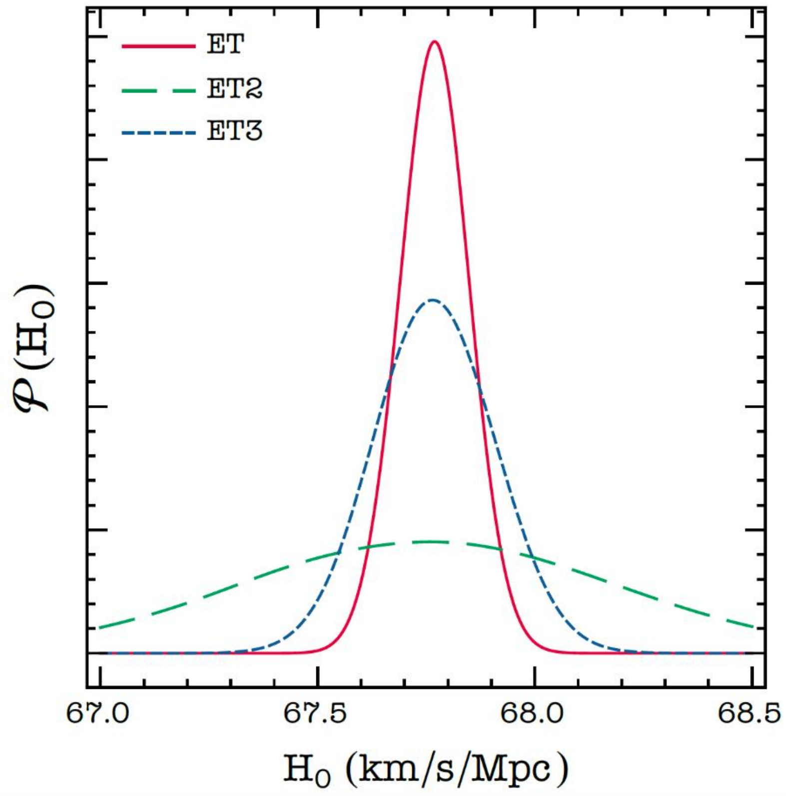
BINARY NEUTRON-STAR LOCALIZATION

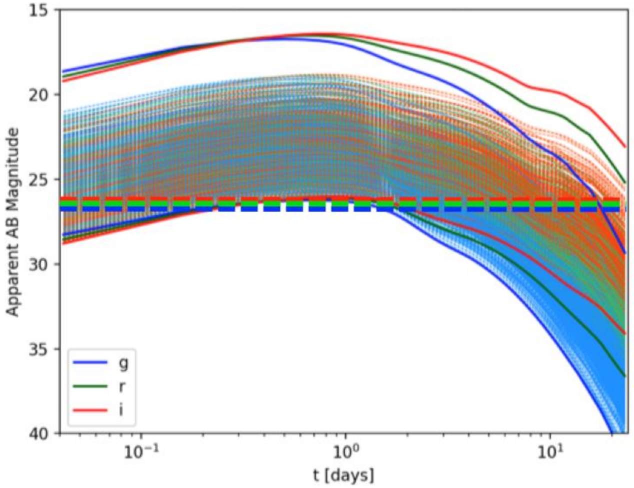


	#events sky-localization < 20 deg²	< 100 deg²
ET-S1	3	8
ET-S2	10	60
ET-S3	40	290
ET	150	1110

HUBBLE COSTANT



KILONOVA EMISSION



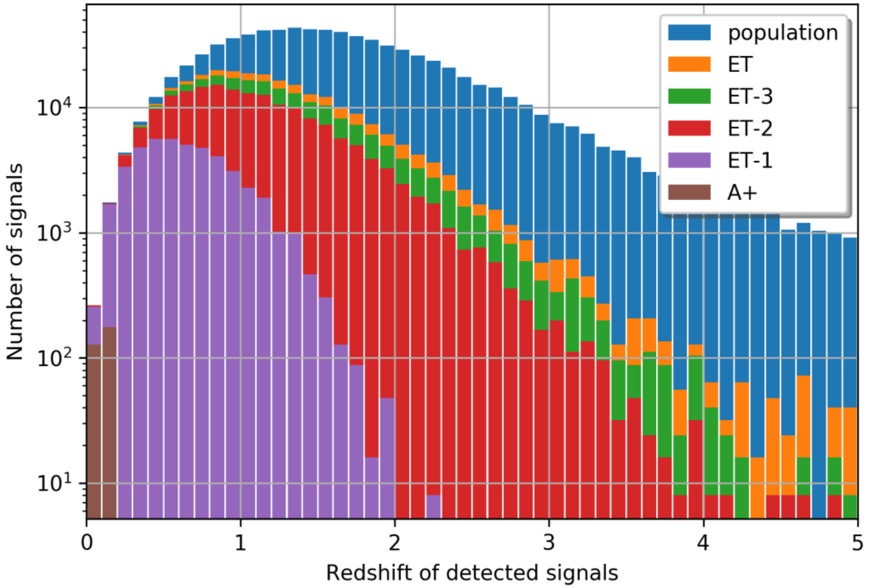
VRO
Exp=600 s

VERA C. RUBIN OBSERVATORY

Cosmology: Hubble constant measurements from GW standard sirens

Q1: science Impact

BINARY NEUTRON STARS

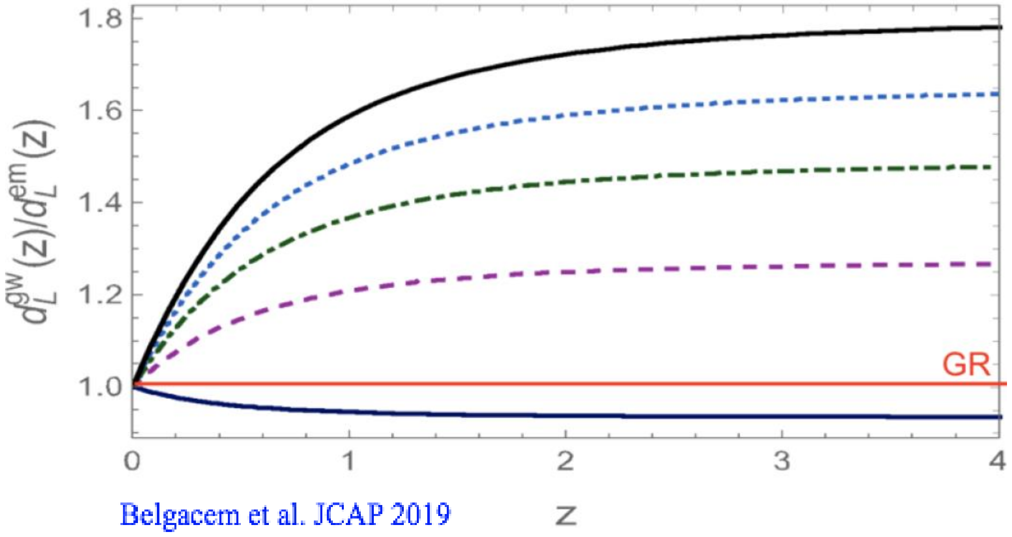


High-redshift

HIGH ENERGY COUNTERPARTS

Cosmology and dark energy with ET

Modified GW propagation



Belgacem et al. JCAP 2019

Reaching large redshift with precise measurements to estimate **cosmological parameters** and **test effects of modified gravity**

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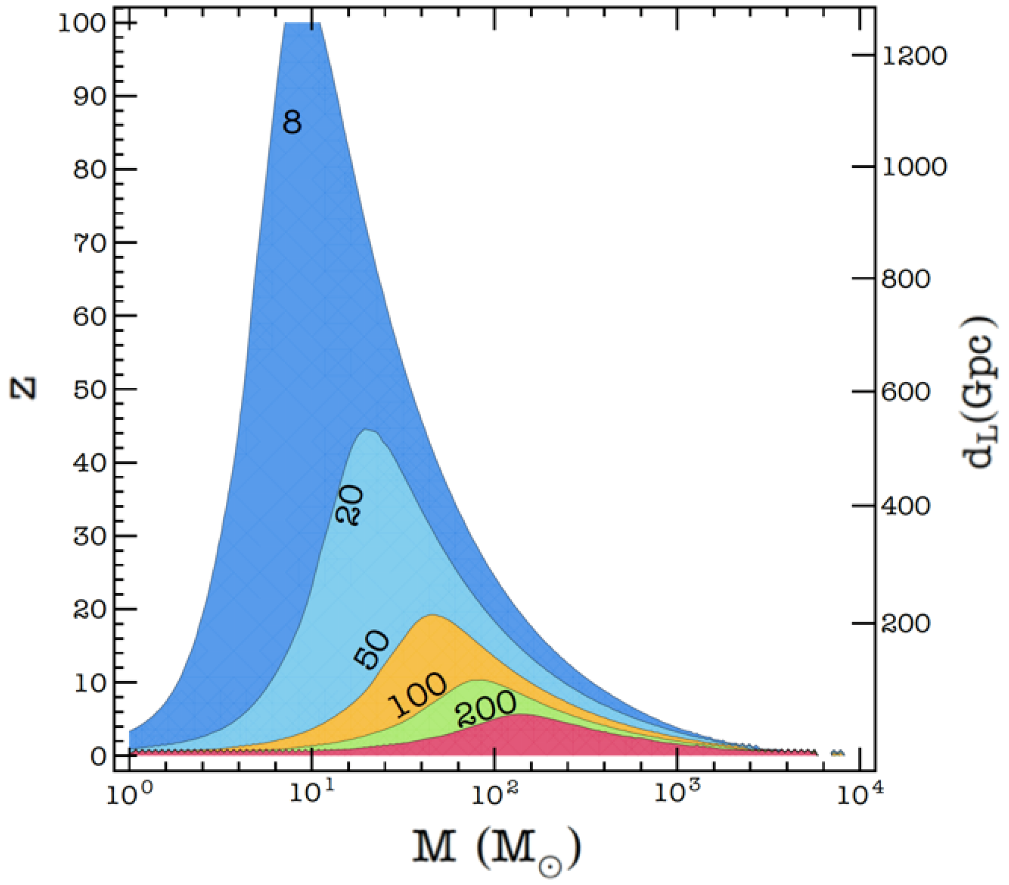
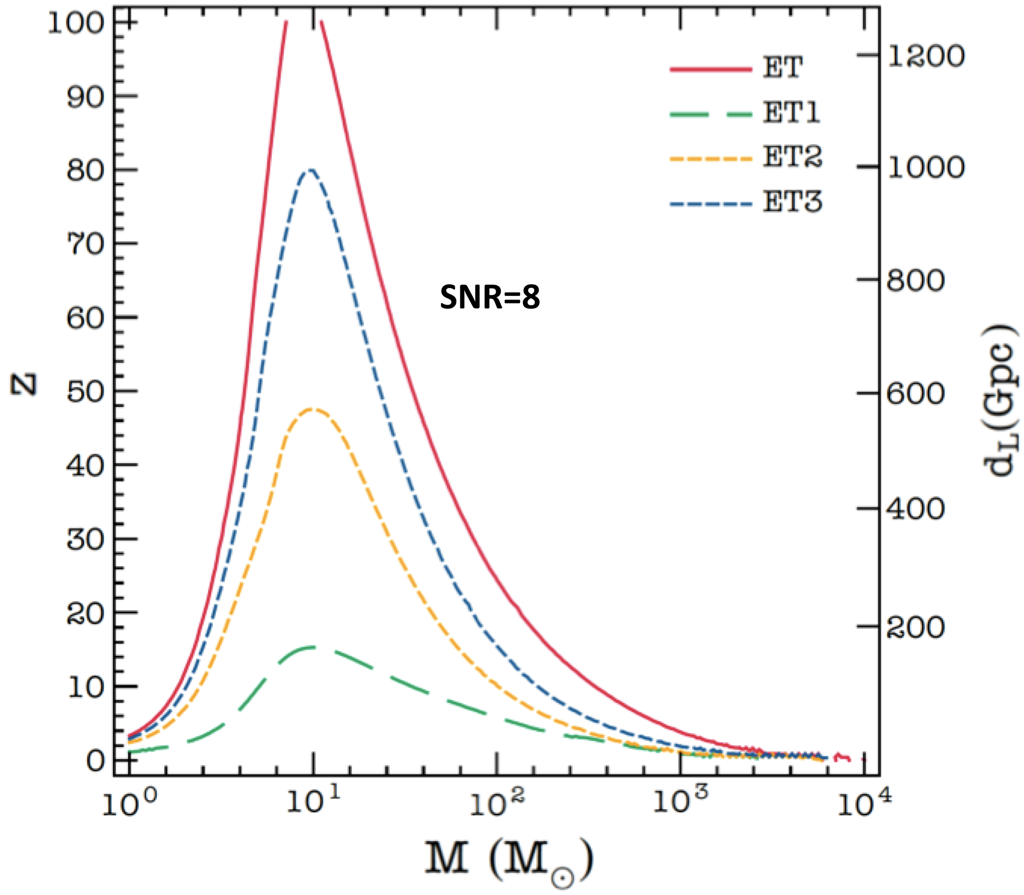
Q1: science Impact

EINSTEIN TELESCOPE

MASS COVERAGE and **INTERMEDIATE MASSIVE BHs**



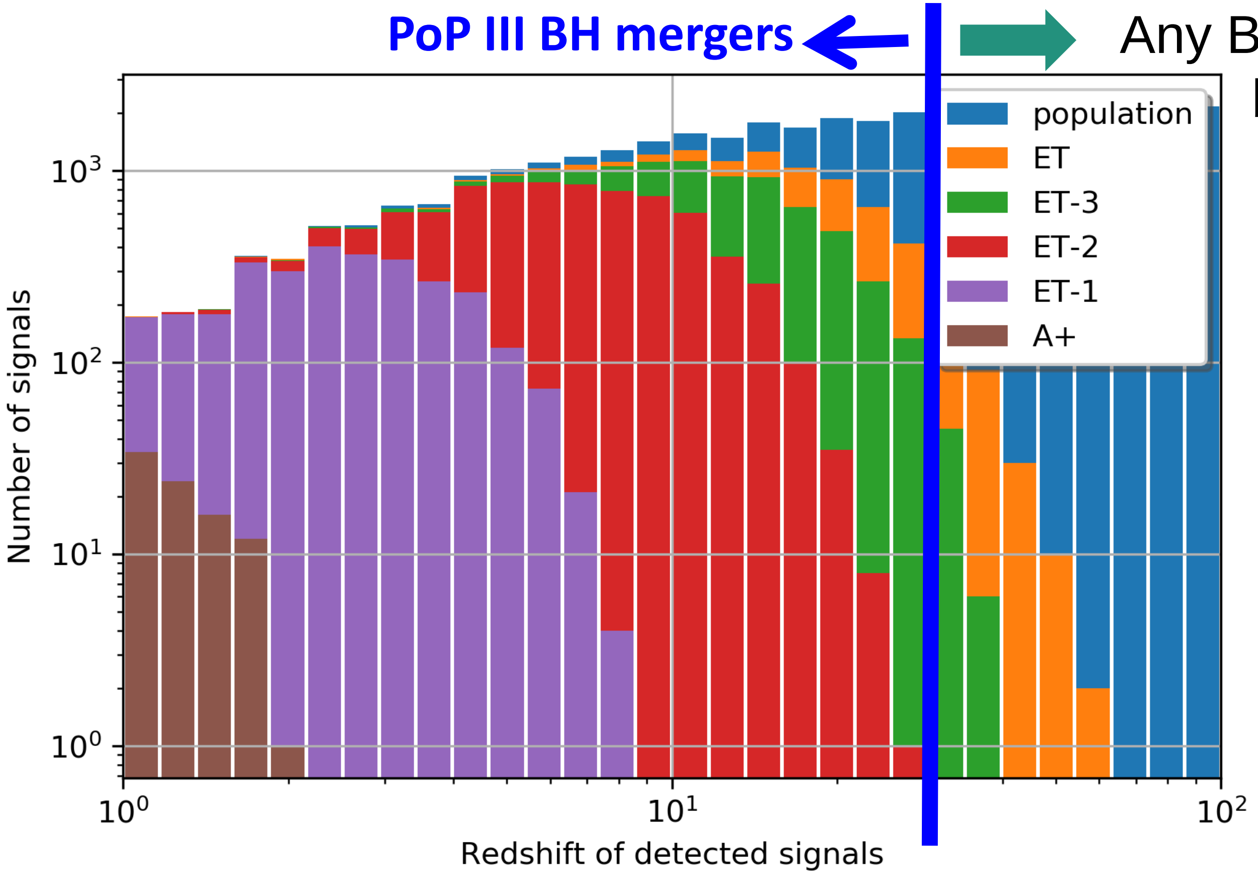


Detecting **intermediate massive BHs** in the volume of the Universe where these rare events are expected to happen

Q1: science Impact

PRIMORDIAL BLACK-HOLES

Disentangle astrophysical PoPIII from primordial BHs

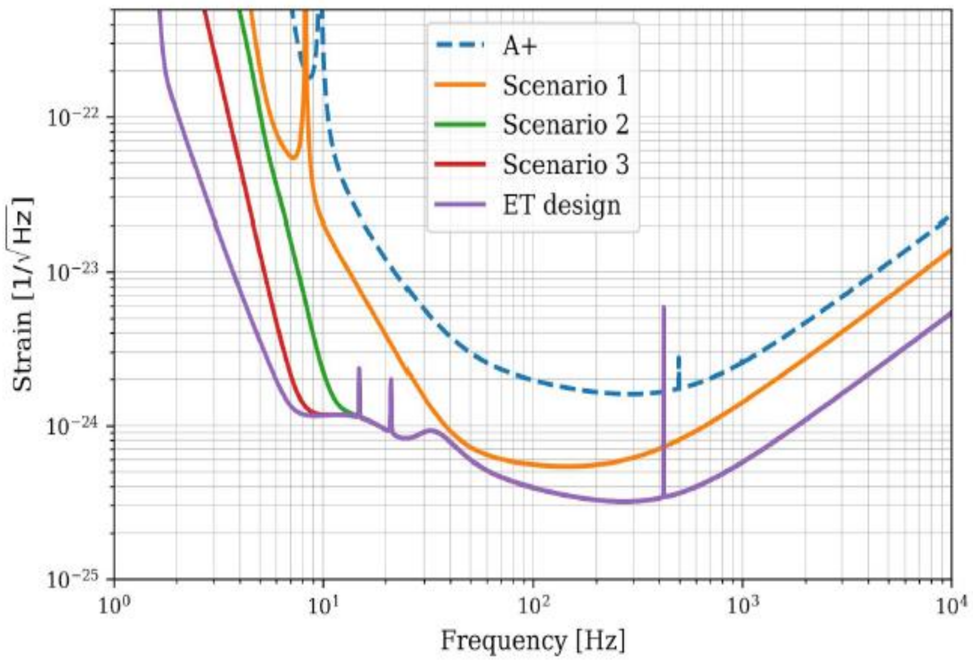


Any BBH merger at z>30 will be of primordial origin

Precise redhsift estimates and statistics to confidentially detect **primordial black-holes**

Q1: Technological Risk mitigation

- The most relevant risk mitigation tool for ET-HF is the development of the Advanced detectors expected in the next 5-7 years
  - The update programme of the 2G/2G+ interferometers is crucial
- In the low frequency regime and in the cryogenics aspects there are important risk reduction activities:
  - KAGRA experience
  - ETpathfinder
  - SarGrav
  - A network of cryogenic and technological facilities in Europe (Rome, Hannover, …)



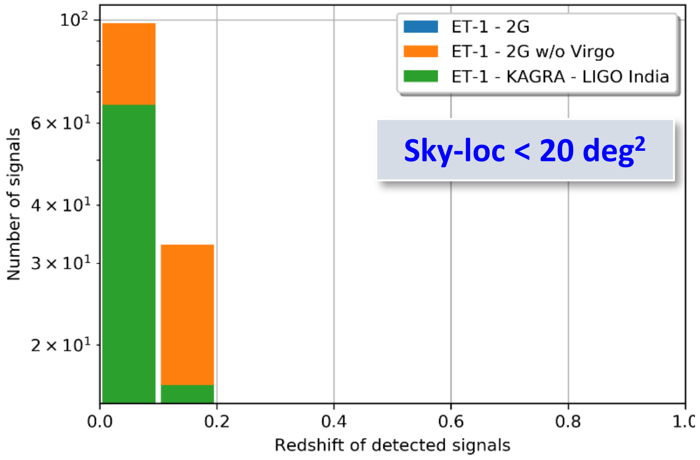
Science degradation →

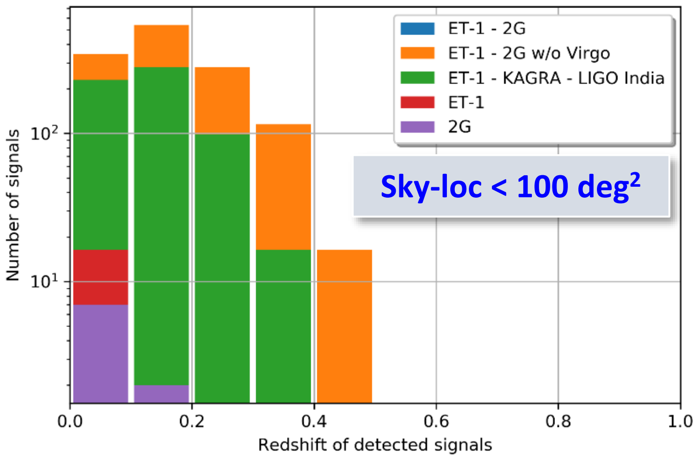
Probability	Low	Medium	High
Improbable			Scenario 1
Possible			Scenario 2
Probable	Scenario 3		

*It evaluates the risk to get stuck in one of the intermediate scenarios 5 years after the beginning of the commissioning

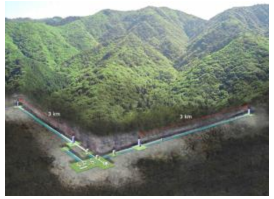
Q2: The global GWD network

ET-S1 + 2G network (LIGOs, Virgo, KAGRA, LIGOIndia)





# BNS events	sky-localization < 20 deg²	sky-localization < 100 deg²
ET-S1	--	16
ET-S1+KI	80	620
ET-S1+HLKI	130	1300
ET-S1+HLKIV	130	1300



ET-S1 needs the 2GWD network to localize BNS



Advanced GW detectors+

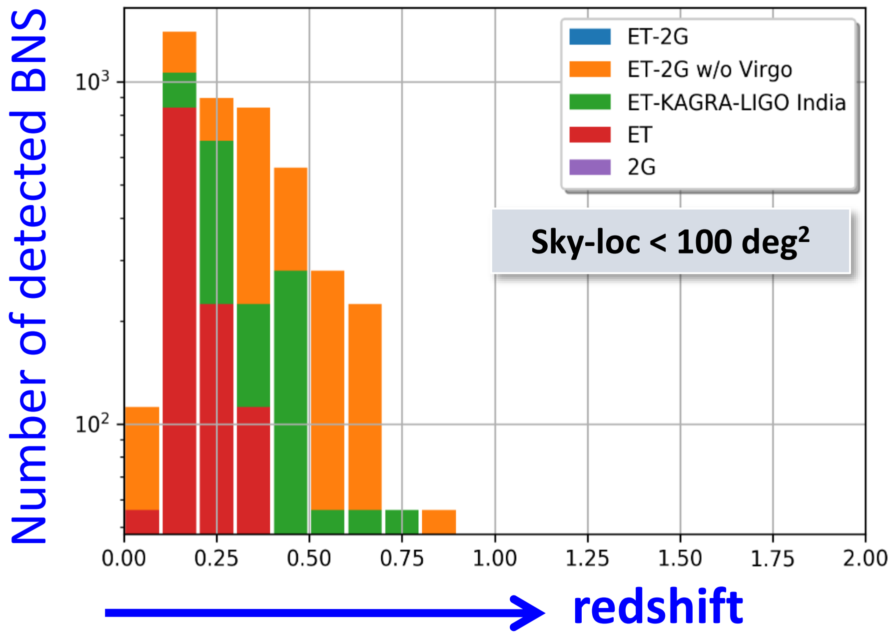
All the simulations use an SNR detection threshold of 8

Q2: The global GWD network

ESFRI

ET EINSTEIN TELESCOPE

ET+ 2G detector network (Virgo, LIGO-Hanford, LIGO-Livingston, LIGO-India, KAGRA)



Number of BNS events with sky-loc	< 20 deg^2	< 100 deg^2
ET	125	1230
ET+KI	233	2640
ET+HLKI	435	4420
ET+HLKIV	437	4420

Kagra and LIGO-India improve the sky localization

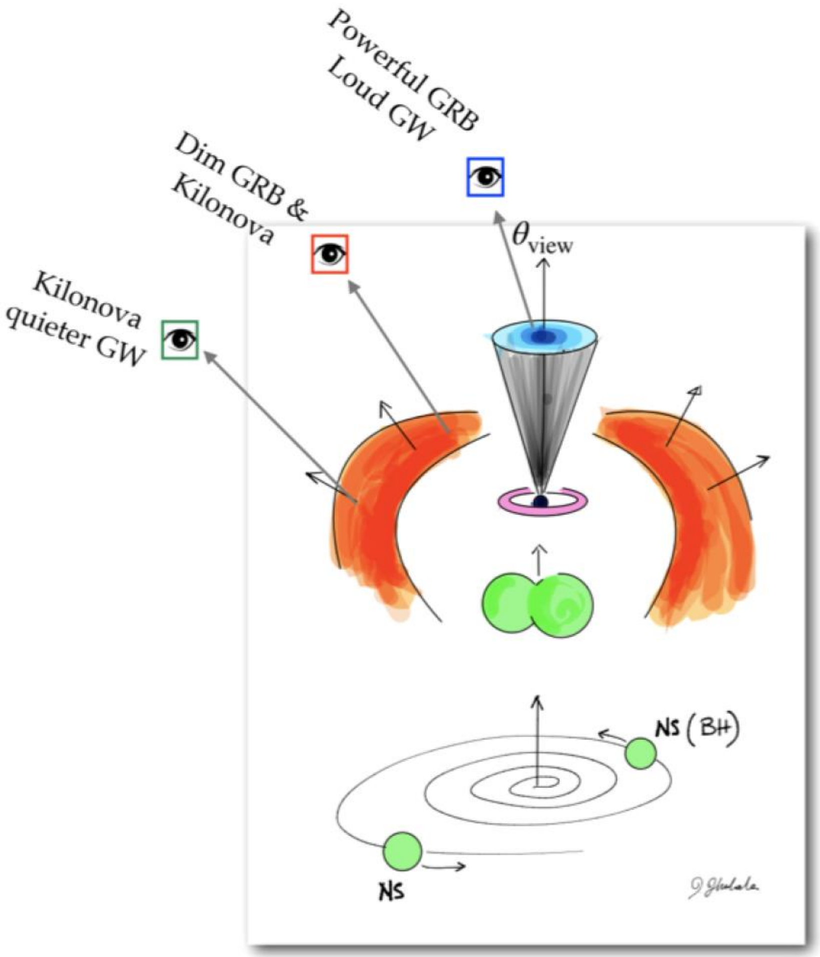
Due to its close proximity to ET, Virgo **does not improve** sky localization

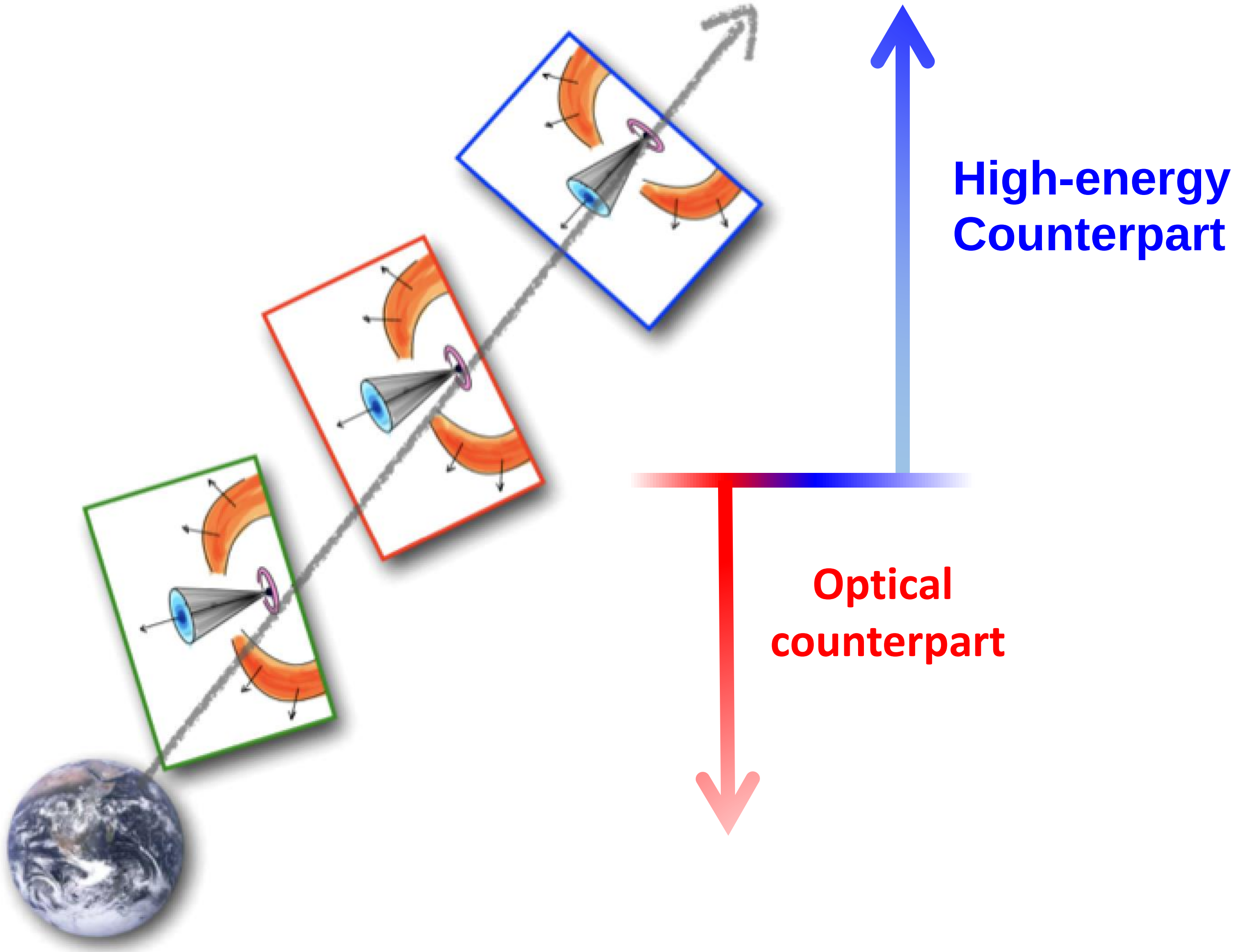
Operating with 2G detector network improves the ET sky-localization capability up to a redshift of about 0.6 (3.5 Gpc)

→ **Multi-messenger science, cosmology, nuclear physics**

Q03:Multi-messenger observatories

SEARCH PHASE: two regimes **nearby Universe** and **remote Universe**



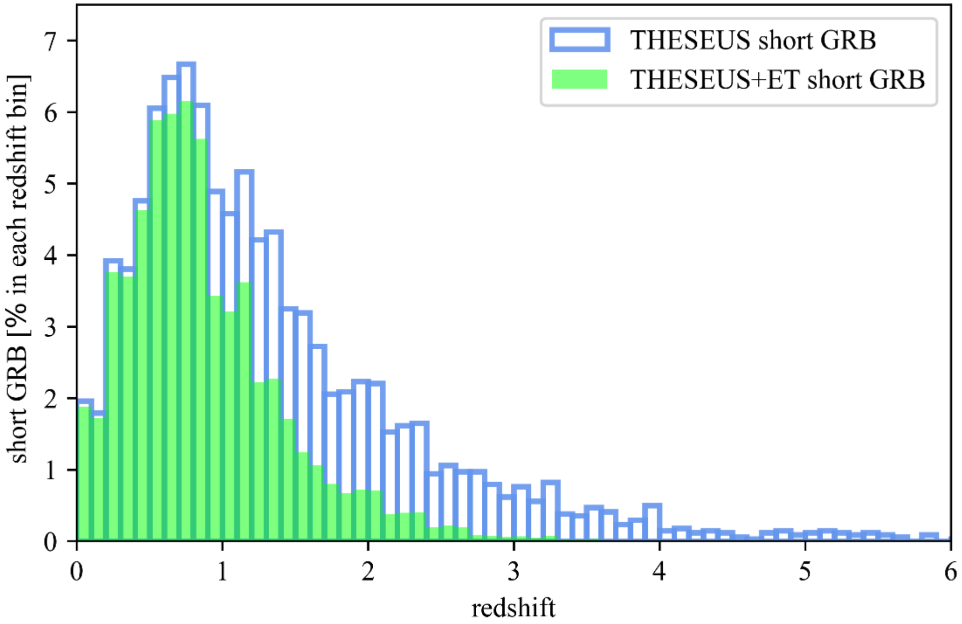


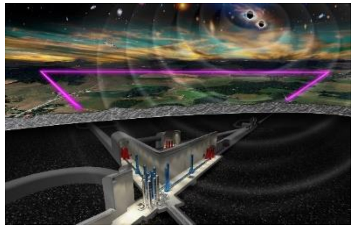
Q03:Multi-messenger observatories

SEARCH PHASE, REMOTE UNIVERSE: HIGH ENERGY SATELLITES

- γ/X-ray satellites (such as SVOM, Einstein Probe, the mission concepts THESEUS and AMEGO) observe in **survey mode**
  → **no necessity to interrupt other observations**

Short γ-ray burst





THESEUS-ET joint detections 10 per year

Multi-messenger observatories

SEARCH PHASE: OPTICAL WIDE FoV TELESCOPES in the NEARBY UNIVERSE

- Observations with the appropriate sensitivity and cadence

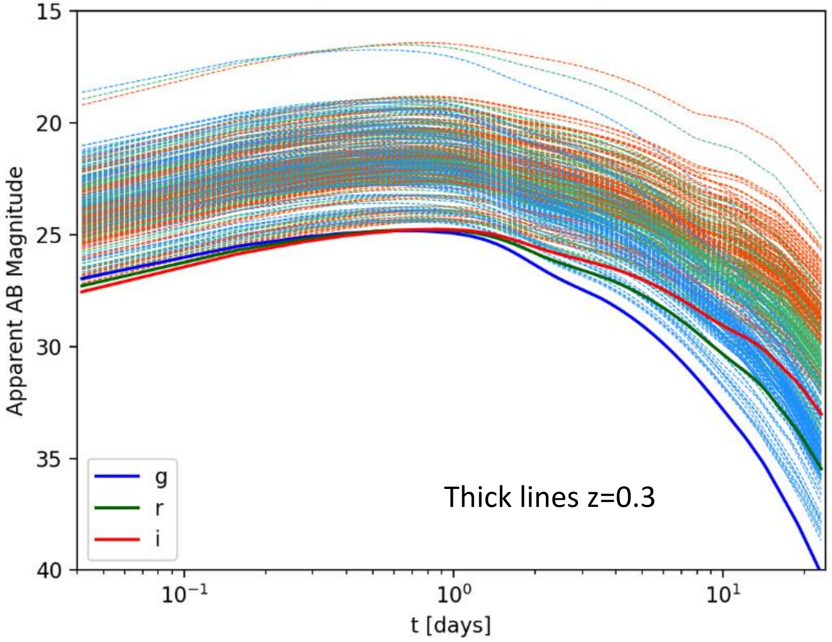
→ **necessity to ask telescope time**

VERA RUBIN OBSERVATORY FOLLOW-UP:

- three epochs of 600s observations in two filters
- detection efficiency is larger than 99% up to z=0.3

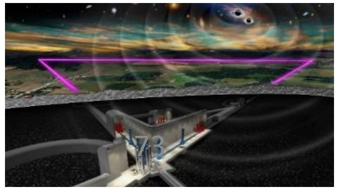
	Joint GW/VRO detections per year	Fraction of VRO telescope time
ET	60	6%
ET+HLKIV	170	17%

ET sky-localization < 20 deg^2



A hundred of counterparts per year can be detected with a reasonable amount of telescope time

VERA C. RUBIN OBSERVATORY



Q03:Multi-messenger observatories

CHARACTERIZATION PHASE: spectroscopy and deep observations

- **The most time expensive phase**

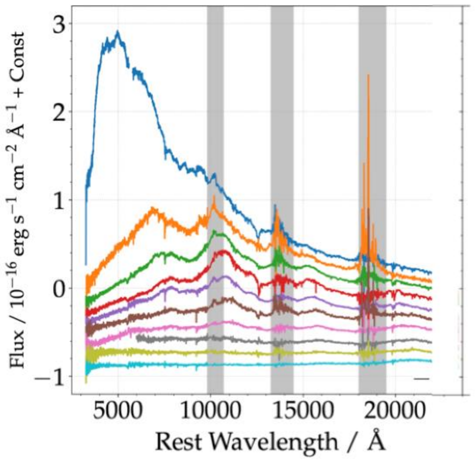
HOST GALAXY REDSHIFT

- Spectroscopic surveys (WAVES, DESI, MSE) will measure the z for several milions of galaxies

A hundred detections per year will have redshift measurements

TRANSIENT SPECTRA and DEEP FOLLOW-UP

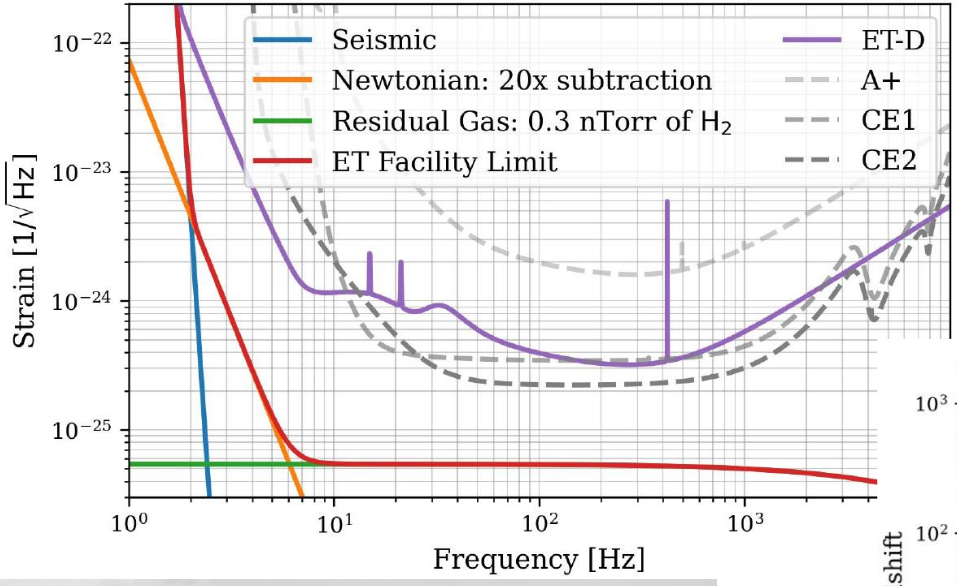
- Time request in expensive larger telescopes, such as VLT, JWST, TMT, ELT

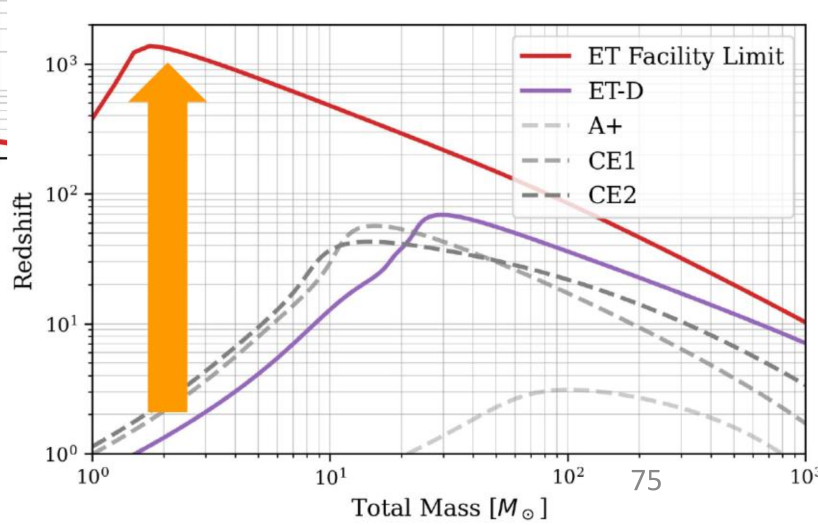


Several tens of transients are expected to be completely characterized

Facility limits evaluation

- The ET infrastructure is studied to host for decades the subsequent upgrades of the ET interferometers
  - A key activity is to define the infrastructure specifications and to realise it in order to fit that requirement





Q05: Open Access in ET

- In GW physics, cooperation works better than competition:
  - The full panorama of science targets can only be pursued by sharing data of all the GW detectors
  - Multimessenger Astronomy requires sharing of data between different kind of observatories and different communities
- In ET we will follow the path created by Virgo and LIGO:
  - Open and Public Access (OPA) to alerts
  - Limited period of property data (currently 18 months)
    - Calibration, data quality, internal analysis
    - Releasing short chunk of data around published events
  - Open Access to data implementing the FAIR principles